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Sexual Dimorphism in Anthropometric Measurements of Adult Uttarkashi (India) Individuals: A Forensic Anthropological Study

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Abstract. Biological profiling of unknown human remains is the foremost task required in forensic/medico-legal death investigations and sex determination of such remains is an important element of biological identity of an individual. In present study, 12 anthropometric measurements were recorded on 298 Uttarkashi individuals (150 males and 148 females) between age group of 18-25 years. Majority of measurements were found to have a significant degree of sexual dimorphism among them; being highest for cubit and thumb lengths and lowest for left palm and right foot lengths (p >0.001). From Univariate discriminant function analysis, cubit length and left foot length were selected as the best variables to discriminate sex of about 80% (84% males and 76% females) 79% (84.7% males and 73.6% females) individuals, respectively. Similarly, 86% subjects could be classified to their correct sex category from all the lineal measurements (88.5% males and 87.2% females) or the hand measurements only (83.1% males and 84.6% females) from the multivariate discriminant function analysis. The results of present study can be considered an addendum to the existing population data for forensic anthropological literature.

Keywords: Forensic anthropology; Biological profiling; Sex determination; Uttarkashi individuals; Lineal bodily measurements.

1. Introduction

Forensic anthropology involves the application of anthropological knowledge, research and techniques in medico-legal contexts for identification purposes. Forensic anthropologists often work with human remains retrieved from a variety of situations like disasters, accidents, war or war-related crimes from where heaps of

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decomposed bodies, badly damaged, charred or commingled osseous remains (bones and teeth) along with some contextual items are recovered. Establishment of biological identity (age, sex, stature, ethnicity, trauma etc.) of such human remains is a very challenging task for a forensic anthropologist involved for this pursuit[1,2]. Sometimes, only dismembered body segments (commingled with contextual items) are recovered from the site of mass causalities and anthropometric measurements of such fragmented or displaced body parts is the only option left with the investigators to establish the biological identity of the victims. No two individuals are exactly alike either in their visible physical features or in their measurable body dimensions and; even genetically identical (monozygotic) twins differ in majority of these aspects. The individuals of two sexes and of different population groups are exposed to varied degrees of environmental (climatic, hormonal, psychological etc.), genetical and nutritional factors and thus, have different rates of growth and developments[3,4]. It is these differences which have been used for comparisons between individuals and quantifying variations to be utilized for identification purposes in forensic anthropology. The intensity, duration and quantum of two adolescent spurts (occurring in each individual) also differ in the members of two sexes, thus inculcating sexual dimorphism in their body physique, composition and dimensions. On an average, female body is roughly 92% in dimensions of a male individual. Thus, biological differences in dimensions and proportions of body physiques and individualized body parts of persons of two sexes and of different population groups have significant practical applications in forensic anthropological identifications. The individual body segments are firstly segregated into two sexes according to their surface morphologies and items of personal identity and their measured values are put into regression or discriminant equations available for individuals of that particular population group. The mortal remains of some Indian political leaders killed in terrorist attacks in recent past were identified on the basis of anthropological characteristics of their body parts recovered from the site debris.

Determination of sex from unknown human body segments or skeletal remains is an important step of the identification process in any medico-legal investigation and is comparatively an easy task than other components of biological profile to be established by forensic anthropologists[5]. Sex estimation just halves the chances of identification and retrieval for any unknown, missing or deceased person/s as subsequent methods of biological profiling depend upon accurate sex estimates[6,7]. The accuracy and reliability of sex estimates depend upon the preserved body segments or available anatomical portion of human body for the purpose[8]. For sex determination, forensic anthropologists traditionally rely upon the expected size differences and degrees of sexual dimorphism between individuals of two sexes and among individuals of different population groups. The latter is important for effectiveness of metric standards[9]. A number of techniques have been suggested to quantify sexual dimorphic features of the human morphologies and; anthropometry is one of such methods to study variations in bodily dimensions. Anthropometry is a technique of taking measurements on human body at specific universal anatomical landmarks using standardized instruments. It has been used as a gold technique since years for studying variations in human body dimensions and proportions between two sexes living in different geographical regions of the globe. A number of studies have been reported in the literature regarding sexual differences in human body segments among different population groups and different discriminant equations have been suggested for sex estimation of an unknown individual belonging to a particular population group. Such discriminant standards are population-specific and cannot be used for sex determination of an individual belonging to another population[5,7]; there arises a need for generation of sex determination discriminant or regression formulas for separate population groups.

Indian population is heterogeneous cluster comprising of various sub-population groups; classified and identified on the basis of some similarities in the morphological, biological, genetical or serological features of individuals of a specific population cluster[10,11]. Majority of Indian population groups have been studied anthropologically, but no forensic anthropology study have been reported in the literature for sex determination of Uttarkashi individuals. Uttarkashi is a mountainous region of the state of Uttarakhand (India) whose inhabitants can be easily identified to the area based upon their visually distinct morphoscopical features and bodily dimensions. This geographical region has different nutritional, environmental and socio-cultural conditions when compared with their neighbouring population groups living in Gangatic Indian plains. Present study was formulated to investigate the degree of sexual dimorphism and; sex estimation accuracies of 12 bodily linear dimensions of head, hand and foot of adult Uttarkashi individuals. The results of present study are expected to help in sex estimation of any unknown individual belonging to mountainous region of Uttarkashi from the anthropometric body segments and derived discriminant function equations when human remains are retrieved from forensic anthropological contexts.

2. Materials and methods

Twelve anthropometric measurements were recorded on 298 Uttarkashi individuals (150 males and 148 females) between age group of 18-25 years. The measured variables include both mid-facial (stature, head length, morphological facial height, physiological facial height mouth width) and bilateral (ear length, nose length, hand-length, cubit length, palm-length, foot length and thumb length) measurements on head and extremities. The definitions of landmarks used, name of instrument and the techniques followed have been shown in Table 1, and diagrammatically represented by Figures 1 to 3.

Figure 1. Estimation of stature (H) using anthropometric rod.

The subjects having any bodily disfigurement, fractures, congenital defects or displacements were neglected for data collection for present study. The recorded measurements were inserted in Microsoft excel spreadsheet and statistical analyses were done using SPSS software (Version IBM 20.0)[12]. The descriptive were calculated and independent t-test was applied to find statistical significance of differences between mean values of a variable in two sexes. Both univariate and multivariate discriminant function analyses were done to estimate the best variable or combination of variables for most accurate sex estimation of Uttarkashi individuals. The recorded measurements were compared with already published studies and Student's t-test was calculated to report statistical significance of differences in recorded bodily measurements.

Figure 2. Investigator taking the hand measurements using sliding calliper (HL).

Figure 3: Anthropometric measurement technique of Head Length using spreading calliper (HL).

Table1. Landmarks/instruments used and the definitions for various measurements used in present study

Variable	Landmarks used	Definition of landmark/s used	Instrument used	Scheme/Technique of measurement taken
Height/Stature (H)	Ground to vertex	Vertex is highest point on top of the head in mid-sagittal plane	Anthropometric rod	The movable arm of the anthropometric rod is allowed to touch the vertex point and lower point of rod touches ground; when the person is standing upright on the ground and measurement is taken from left side of the subject[2] (Figure 1)
Head length (HDL)	Glabella to Opisthocranion	Glabella is mid-point between brow-ridges and opisthocranion is the most posterior point on back of the head in mid-sagittal plane	Spreading caliper	Two arms of the caliper are placed at respective points i.e., Glabella and Opisthocranion of the subject and reading is recorded[2,23] (Figure 3)
Ear length (EL)	Supra-aurale to Sub-aurale	These are uppermost and lowermost points on helix of the ear-lobe, respectively	Sliding caliper	The fixed arm of the caliper is placed at supra-aurale and the movable arm is touched at point sub-aurale of each ear and measurement is recorded[25]
Morphological facial length (MFL)	Glabella to Gnathion	Gnathion is lowest point on mandible in mid-sagittal plane	Sliding caliper	The upper end of the caliper is pointed at Glabella and the other point is at Gnathion and measurement is recorded
Physiological facial length (PFL)	Trichion to Gnathion	Trichion is the point on median plane of hair line where forehead cuts the sagittal plane	Sliding caliper	The upper end of caliper is pointed at Trichion and the other arm is placed at Gnathion and measurement is recorded
Nose length (NL)	Nasion to Sub-nasale	Nasion is at the junction frontal bone and the nasal root; subnasale where nasal septum meets the philtrum	Sliding caliper	The one arm of the caliper is placed at Nasion and the other arm is at sub-nasale when the subject is standing erect with head in FH plane[24]
Mouth Breadth (ML)	Chelion to Chelion	Chelion is the mouth corner where upper and lower lips meet	Sliding caliper	Both the end of the caliper are allowed to touch the Chelion points
Cubit length (CL)	Tip of elbow to Dactylion	Dactylion is the lowest point on the anterior curved top of middle finger of hand	Anthropometric compass	The one arm of compass is allowed to touch the tip of the elbow and other is touched to the Dactylion[22,26]
Hand length (HL)	Dactylion to mid of Stylion	-do- Stylion is deepest point on styloid process of radius	Sliding caliper	The fixed end of the caliper is touched with the Dactylion point and the other arm is touched with the midpoint of Styloid process[22,26] (Figure 2)
Palm length (PL)	Base of middle finger to inter-stylion line	Stylion is deepest point on styloid process of radius	Sliding caliper	The fixed end of the caliper is placed at the base of middle finger and the other end is touched with the inter-stylion line
Foot length (FL)	Pterion to the longest Acropodian	Pterion is the hindmost point of the heel; acropodian is the most forwardly placed point on the 2nd or 3rd toe)	Sliding caliper or Anthropometric compass	The two arms of caliper or compass are allowed to touch the Pterion point and the Acropodian point[22,26]
Thumb length (TL)	Tip of thumb to the end of the thumb bone	--	Sliding caliper	The one arm of the caliper is placed at the tip of the thumb and other at the end of the last digit of thumb towards palm

3. Results

The detailed statistics of all the anthropometric measurements has been shown in Table 2. The mean value of height in males and females was 165.88±13.77 cm and 154.59±5.72 cm, respectively and difference in height between two sexes was found statistically significant ($p<0.001$). The mean values of all the anthropometric variables were found statistically higher in males than the females. Analysis of bilateral asymmetry was not among the objectives of present study, the bilateral variables showed slight differences between right and left side measurements. Right foot length (FLR) showed highest index of sexual dimorphism, followed by palm length of left hand, cubit length of right hand and so on; the least index was exhibited by head length, morphological facial height and nose length.

Table 3 shows the results of univariate discriminant function analysis. Left cubit length and foot length showed highest value of R-square, Eigen value and canonical correlation coefficient, followed by right cubit length and left thumb length, signifying that these variables are highly correlated with sex of an individual. The cubit length and left foot length were selected as the best univariate variables to discriminate sex of about 80% (84% males and 76% females) 79% (84.7% males and 73.6% females) individuals, respectively. Left palm length and mouth length showed maximum sex biasness, biased towards females (-21.2%) whereas sex estimation accuracy was biased maximum in left foot length towards males (11.1%). Similarly, the minimum sex biasness was noticed for nose length (-0.7%) and right thumb length (-1.6%), towards females). The anthropometric dimensions which include measurements between soft cartilaginous or muscular landmarks like mouth width, nose length and ear length were selected as the poorest indicators of sex to estimate sex of 55% to 66% individuals to their correct sex category. From the standardized and unstandardized discriminant function coefficients/scores presented in Table 2, discriminant equations can be developed to estimate sex of an unknown person with the depicted accuracies in the table.

Table 2. Descriptive Statistics of Studied Variables. H: Stature, HL: Head length. ELL: Left Ear Length. ELR: Right Ear Length, MFL: Morphological facial length, PFL: Physiological facial length, NL: Nose length, ML: Mouth length, CLL: Left cubit length, CLR: Right cubit length, HLL: Left hand length, HLR: Right hand length, PLL: Left palm length, PLR: Right palm length, FLL: Left foot length, FLR: Right foot length, TLL: Left thumb length, TLR: Right Thumb Length.

Variables entered	MALES(N=150)				FEMALES(N=148)				d	ID	t-values
	Mean±SD	Range Max-min	Variance	SEE	Mean±SD	Range Max-min	Variance	SEE			
H	165.88±13.75	184.50-16.35	189.210	1.12	154.59±5.72	174.00-139.30	32.701	0.47	10.89	107.3	9.273**
HDL	17.84±1.35	20.50-14.90	1.832	0.11	17.02±1.21	19.20-13.40	1.467	0.99	0.82	104.8	5.479**
ELL	5.96±0.40	7.00-5.00	0.166	0.03	5.61±0.36	6.70-4.00	0.127	0.29	0.35	106.29	8.040**
ELR	5.97±0.39	7.00-5.10	0.159	0.033	5.61±0.36	6.60-4.60	0.132	0.29	0.36	106.49	8.246**
MFL	17.54±1.01	20.70-15.00	1.029	0.83	16.63±0.95	19.40-11.00	0.897	0.078	0.90	105.46	7.984**
PFL	11.81±0.81	15.90-9.90	0.644	0.66	11.14±0.84	13.40-7.40	0.706	0.69	0.66	106.01	7.033**
NL	5.55±0.52	6.90-4.40	0.269	0.42	5.25±0.45	6.70-4.30	0.203	0.04	0.3	105.56	5.193**
ML	5.15±0.51	6.50-3.90	0.267	0.42	4.85±0.37	5.80-4.00	0.134	0.03	0.3	106.16	5.773**
CLL	41.89±3.15	48.40-18.20	9.961	0.26	37.12±2.92	43.10-28.00	8.500	0.24	4.77	112.86	13.566**
CLR	41.68±3.66	48.50-17.90	13.371	0.29	37.19±2.87	43.20-28.10	8.208	0.24	4.49	112.07	11.802**
HLL	18.61±2.27	42.80-14.20	5.134	0.18	16.88±1.18	19.10-13.70	1.392	0.097	1.73	110.23	8.271**
HLR	18.90±5.84	81.60-1.50	34.054	0.47	16.92±1.16	19.10-13.60	1.354	0.096	1.98	111.71	4.078**
PLL	10.64±4.85	69.30-8.90	23.602	0.39	9.41±0.61	11.00-7.00	0.369	0.05	1.24	113.13	3.090**
PLR	10.35±1.28	24.30-8.90	1.655	0.10	9.39±0.59	11.00-7.80	0.344	0.48	0.96	110.25	8.324**
FLL	24.86±1.32	27.90-20.50	1.754	0.10	22.37±1.86	26.10-17.20	3.458	0.15	2.49	111.15	13.322**
FLR	26.04±16.43	24.50-6.50	2.70	0.34	22.17±2.68	26.20-2.60	7.192	0.22	3.88	117.49	2.851**
TLL	6.33±0.50	7.80-5.00	0.250	0.04	5.76±0.47	7.20-4.40	0.218	0.04	0.56	109.79	10.064**
TLR	6.38±0.95	16.20-5.10	0.894	0.08	5.80±0.49	7.90-4.70	0.23	0.04	0.58	109.95	6.653**

Table 3. Results of univariate discriminant function analysis for sex estimation.

Variables	Wilk's lambda	R^2	F Ratio	Eigen value	Canonical Correlation	CDFC	GC		SP	FDFS		Accuracy % from DFA			
							M	F		M	F	M	F	SB	O
HDL	0.908	0.918	29.979	0.101	0.303	0.118 C=-13.569	0.315	-0.319	-0.4745	10.807 C=-97.077	10.313 C=-88.471	68.0	58.1	9.9	63.1
ELL	0.821	0.178	64.520	0.218	0.423	2.615 C=-15.13	0.462	-0.468	-0.696	40.775 C=-122.270	38.341 C=-108.191	73.3	68.9	4.4	71.1
ELR	0.813	0.186	67.919	0.229	0.432	2.619 C=-15.163	0.474	-0.481	-0.7145	40.9 C=-122.950	38.452 C=-108.475	68.7	66.9	1.8	67.8
MFL	0.823	0.177	63.687	0.215	0.421	1.019 C=-17.409	0.459	-0.465	-0.6915	18.204 C=-160.333	17.262 C=-144.239	70.7	62.2	8.5	66.4
PFL	0.857	0.142	49.490	0.167	0.378	1.218 C=-13.978	0.405	-0.410	-0.61	17.512 C=-104.123	16.519 C=-92.733	68.7	60.8	7.9	64.8
NL	0.917	0.083	26.919	0.091	0.289	2.059 C=-11.121	0.299	-0.303	-0.4505	23.512 C=-65.892	22.274 C=-59.209	54.7	55.4	-0.7	55.0
ML	0.899	0.100	33.183	0.112	0.317	2.230 C=-11.161	0.331	-0.336	-0.499	25.628 C=-66.727	24.139 C=-59.280	55.3	72.3	-17	63.8
CLL	0.619	0.383	183.818	0.621	0.619	0.329 C=-13.006	0.780	-0.791	-1.1755	4.537 C=-95.729	4.020 C=-75.306	83.3	77.7	5.6	80.5
CLR	0.681	0.319	138.844	0.469	0.565	0.304 C=-12.003	0.678	-0.687	-1.0215	3.857 C=-81.086	3.442 C=-64.707	84.0	75.0	9	79.5
HLL	0.813	0.186	67.875	0.229	0.432	0.553 C=-9.8111	0.474	-0.480	-0.714	5.683 C=-53.580	5.155 C=-44.219	76.0	72.3	3.7	74.2
HLR	0.947	0.052	16.422	0.055	0.229	0.237 C=-4.246	0.233	-0.236	-0.351	1.061 C=-10.727	0.950 C=-8.734	68.7	79.1	-10.4	73.8
PLL	0.969	0.030	9.422	0.32	0.176	0.288 C=-2.887	0.177	-0.179	-0.2665	3090.882 C=-5.386	0.780 C=-4.360	65.3	86.5	-21.2	75.8
PLR	0.812	0.188	68.685	0.232	0.434	0.988 C=-9.853	0.477	-0.483	-0.7185	10.309 C=-54.044	9.350 C=-44.586	73.3	77.7	-4.4	75.5
FLL	0.624	0.375	178.27	0.602	0.613	0.620 C=-14.653	0.768	-0.779	-1.1575	9.564 C=-54.044 C=-119.604	8.604 C=-96.945	84.7	73.6	11.1	79.2
FLR	0.974	0.026	8.028	0.027	0.162	0.085 C=-2.042	0.163	-0.165	-0.2455	0.187 C=-3.124	0.159 C=-2.454	74.7	77.0	-2.3	75.8
TLL	0.745	0.255	101.182	0.342	0.505	2.067 C=-12.487	0.579	-0.587	-0.8725	27.004 C=-86.053	24.595 C=-71.504	70.7	78.4	-7.7	74.5
TLR	0.871	0.128	43.912	0.148	0.359	1.329 C=8.100	0.381	-0.386	-0.574	11.273 C=-36.660	10.253 C=-30.443	70.7	72.3	-1.6	71.5

The results of multivariate discriminant function analysis (MVDFA) have been reflected in Table 4. All linear bodily measurements were used in stepwise MVDFA in Function-I wherein left cubit length, left hand length, left thumb length, mouth breadth, right ear length and nose length were selected as the best variables to correctly identify sex of 87.2% individuals (86.0% males and 88.5% females) with a sex bias of -2.5% towards females. The group means or centroids for males and females were 1.129 and -1.144 for males and females, respectively, thus the unknown subjects having discriminant scores near to a centroid are predicted as belonging to that group. 84.6 % Uttarkashi subjects (86% males and 83.1% females) were classified to their correct sex category when only hand and palm measurements were considered in Function-III of MVDFA. Thus, it can be concluded that hand measurements (HLL, CLL and TLL) have their significant role in sex determination of present study individuals as these variables were selected as best variables in both functions I and III. The foot and hand measurements only could estimate sex of slightly more than 80% subjects, with a sex bias of 9.6% towards male subjects (Function V). The maximum and minimum differences in sex determination accuracies were noticed for foot lengths (11.1%) and head and face variables (0.4%), respectively. Thus, we can conclude that multitude of variables in MVDFA (Function-I) are more useful for sex determination than individual variables and head measurements are comparatively less efficient in sex determination than hand and foot measurements of Uttarkashi individuals.

4. Discussions

The quantification of variability level in human physical features has remained a great area of interest for biological anthropologists since long times and; anthropometry has evolved as a standard scientific method for measuring variations in human bodily dimensions[2,13,14]. One of the immediate applications of the biological anthropology is in forensic case-work under the ambit of the discipline known as forensic anthropology which may be defined as the application of techniques and methodologies of biological anthropology to identify unidentified human corpses and skeletons in medico legal and humanitarian contexts. Personal identification is the major component of forensic anthropological research around the world.

Table 4. Results of Stepwise Multivariate Discriminant Function Analysis.

Variables entered	Selected variables (Wilk's lambda)	CDFC	Eigen value/ Canonical correlation	SDFC	GC	F to remove	SP	FDFS		Accuracy % from MDFA			
								M	F	M	F	O	SB
Function-I (All variables)	ELR(0.444) NL(0.442) ML(0.444) CLL(0.583) HLL(0.479) TLL(0.456)	ELR(0.509) NL(0.394) ML(0.457) CLL(0.228) HLL(0.2310 TLL(0.6180 Constant (-24.203)	1.300 0.752	CLL=0.692 HLL=0.419 NL=0.191 TLL=0.299 ML=0.205 ELR=0.194	M=1.129 F=-1.144	CLL=99.200 HLL=29.752 NL=5.067 TLL=14.130 ML=6.239 ELR=5.838	1.1365	ELR=25.534 NL=15.551 ML=17.167 CLL=4.451 HLL=5.141 TLL=14.984 Constant= -352.736	24.379 14.657 16.128 3.934 4.615 13.579 -297.752	86.0	88.5	87.2	-2.5
Function II (HDL, ELL, ELR, MFL, PFL, NL, M)	HDL(0.695) ELR(0.751) MFL(0.725) ML(0.685)	HL(0.258) ELR(1.517) MFL(0.505) ML(0.592) Constant (-24.836)	0.492 0.574	HL=0.331 ELR=0.579 MFL=0.495 ML=0.266	M=0.694 F=-0.704	ELR=35.408 MFL=24.175 HL=10.645 ML=6.556	0.699	HL=8.410 ELR=33.802 MFL=13.984 ML=12.923 Constant= -332.549	8.050 31.681 13.279 12.095 -297.789	77.3	77.7	77.5	-0.4
Function-III (CLL, CLR, HLL, HLR, TLL, TL)	CLL(0..665) HLL(0.540) TLL(0.518)	CLL(0.245) HLL(0.263) TLL(0.810) Constant (-19.260)	1.091 0.722	CLL=0.745 HLL=0.476 TLL=0.392	M=1.034 F=-1.048	CLL=114.643 HLL=37.993 TLL=24.498	1.041	CLL=4.409 HLL=5.648 TLL=20.311 Constant= -209.814	3.898 5.100 18.624 -169.726	86.0	83.1	84.6	2.9
Function-IV (FLL, FLR)	FLL(0.624)	FLL(0.620) Constant (-14.653)	0.602 0.613	FLL=1.000	M=0.768 F=-0.779	FLL=178.257	0.7735	FLL=9.564 Constant= -119.604	8.604 -96.945	84.7	73.6	79.2	11.1
Function-V (FLL, FLR, HLL, HLR)	FLL(0.813) HLL(0.624)	HLL(0.187) FLL(0.526) Constant (-15.750)	0.673 0.634	HLL=0.339 FLL=0.848	M=0.812 F=-0.823	FLL=106.459 HLL=13.021	0.8175	Hl=3.513 Fl=8.424 Constant= -138.132	3.208 7.564 -112.38	85.3	75.7	80.1	9.6

Stature, age, sex and ancestry helps in narrowing down the pool of possible victim matches in the forensic investigation process and thus provide useful clues to the investigating agencies in establishing the identification of the individuals. The biometrical proportional relationship existing between different body dimensions can be utilized to resolve crimes related to missing persons in the absence of any other concrete evidence. Such a relationship can help a forensic anthropologist to determine sex of a person from the mutilated and dismembered body parts recovered from forensic contexts[15]. Sex estimation is considered as one of the essential parameters in forensic anthropology casework, and requires foremost consideration. Sex may be taken as a biological category classified on the basis of reproductive attributes, and their roles in sexually reproducing species' which can be used in the classification of individuals into two categories, whereas gender is a socio-cultural entity. Physical anthropologists have traditionally used two criteria of skeletal sex estimation, namely morphological (non-metrical) and metrical; including geometric and morphometric techniques.

Determination of sex from the unknown body segments is an essential component of biological profile to be reconstructed in forensic anthropological endeavours. Different standards and methods developed are generally population-specific and cannot be applied for sex determination of individuals of other population groups. Humans differ with respect to their physical features, bodily size and proportions, skeletal maturity/development and degree of sexual dimorphism[16,17]. The differential rates of intensity and duration of adolescent spurts in two sexes further aggravate the degree of sexual dimorphism in human skeletal features[18,19]. Differences in biomechanical loadings, activity patterns and sexual division of labour might have also added up to an amount of sexual dimorphism in various bodily dimensions of humans and their skeletal framework[18,19]. Indian population is heterogeneous one, divided into various cluster-groups according to some similarity in their morphological, serological, behavioural, demographic and genetical features[10,11]. Uttarkashi is a mountainous region where individuals differ in visible features, bodily dimensions, nutritional and environmental conditions and genetical embodiments from their neighbouring population groups. From the accessible literature, it was noticed that no anthropometric study was available for sex estimation of Uttarkashi (Uttarakhand, India) individuals from their lineal bodily measurements like lengths of extremities, hand, foot, head, facial lengths etc. So, present study was formulated to suggest discriminant function equations for sex determination based on 12 anthropometric measurements recorded on 298 individuals (150 males and 148 females) in the age-group of 18-25 years.

The majority of studied measurements showed a significant degree of sexual dimorphism among them ($p > 0.001$); being highest in cubit length and thumb length, and the lowest in left palm length and right foot length. These results were in coherence with previous studies which reported that cubit length is significantly longer in males than the females[15,20,21]. Table 5 shows a comparative analysis of hand and foot measurements recorded in different population groups by different researchers (-ve sign indicates that value is greater than present study measurements). The careful analysis of various studies revealed that Uttarkashi subjects had significantly smaller feet than the most national and international studies compared, except a study conducted by Sen et al[20] conducted on Rajbanshi (West Bengal) subjects. The hand length was larger than most of studies compared; except for Nigerians[22] and Slovakians females[21] having significantly longer hand lengths than the present study mountainous individuals adapted to different environmental, nutritional and genetical conditions than the African or Slovak individuals. The hand of Uttarkashi people was found slightly longer than the most Indian studies compared; probably due to the fact that people were accustomed to do most of their daily routine works manually than mechanized ones. The differences in genetical, hormonal, nutritional or environmental factors or varied patterns of growth and development in two sexes may be responsible for quantum of these sexual differences in body anthropometrics of different population groups reported in previous studies[13,14,20,23]. Shreshta et al[24] found that average nasal length in Nepali males and females was 4.6+0.31 and 4.3+0.29 cm, respectively, displaying significant sexual differences. Present study subjects had significantly larger noses than the Nepali subjects[24], due to variations in climatic or genetic factors of the two populations. The right and left ear lengths in both the sexes were found significantly smaller than the subjects of plain geographic areas of other states of India. Murgod et al.[25] found that 67.7% Indian individuals (64.7% males and 70.7% females) of different castes and religion were correctly identified to their sex category from their ear measurements. These results were in close comparison with present study findings showing that 67.8 and 71.1% present study individuals were classified to their sex category from their right and left ear lengths, respectively. Such differences in ear lengths and resultant accuracy levels could be again due to inconsistencies in various genetical and environmental factors affecting the facial morphology of the subjects of two studies. Physical growth and skeletal maturity are complex processes which are affected by various genetic, hormonal and environmental factors[3,4,23].

Table 5. Comparative analysis of foot and hand lengths of present study with different population groups.

Authors	Sample size	Foot Length		Hand Length	
		Right	Left	Right	Left
Present Study (2018) Indian	Males (n=150)	26.04±1.43	24.87±1.32	18.90±5.84	18.61±2.27
	Females (n=148)	22.17±2.68	22.37±1.86	16.93±1.16	16.89±1.18
Danbarno[22] (Nigerians)	Males (n=250)	28.39±1.73 (-6.57**)	26.42±1.60 (-10.88**)	19.85±0.86 (-2.00)	19.93±0.93 (-6.96*)
	Females (n=150)	24.52±1.08 (-9.91**)	24.70±1.10 (-13.31**)	18.51±0.66 (-14.34**)	18.52±0.77 (-14.08**)
Kanchan et al [27], Indian	Males (n=120)	-	-	18.3±0.9 (1.25)	18.2±1.2 (1.94)
	Females (n=120)	-	-	16.8±0.8 (1.07)	16.8±0.8 (0.74)
Krishan and Kanchan[15], Indian	Males (n=100)	24.75±1.1 (3.60*)	24.73±1.2 (0.89)	18.27±0.9 (0.71)	18.21±0.9 (3.49*)
	Females (n=100)	22.60±1.1 (-1.74)	22.57±1.1 (-1.07)	16.81±0.8 (0.99)	16.77±0.8 (0.99)
Sen and Ghosh [28], Indian	Males (n=175)	23.95±1.09 (5.97**)	24.01±1.09 (6.62**)	-	-
	Females (n=175)	22.23±1.00 (-0.25)	22.26±1.00 (0.65)	-	-
Uhrova et al [21], Slovakians	Males (n=120)	26.26±1.26 (-0.61)	26.25±1.30 (-8.87**)	18.70±0.89 (0.41)	18.73±0..92 (-0.60)
	Females (n=130)	23.86±0.98 (-7.15**)	23.86±1.00 (-9.71**)	17.21±0.75 (-2.40*)	17.21±0.76 (-2.71*)
Agnihotri et al [29], Indian	Males (n=125)	26.12±1.09 (-0.22)	26.05±1.10 (-8.39**)	-	-
	Females (n=125)	23.33±1.08 (-4.82*)	23.29±1.10 (-5.12*)	-	-

Discriminant function analysis (DFA) is a commonly used statistical tool in forensic anthropology for discrimination between two groups or categories like males and females. It explores the differences between two or more groups by determining the set of combination of variables which can best predict the group membership. In forensic anthropology, DFA requires a suite of measurements taken on human body or bones to ascertain which measurement/s are the best predictors of sex category of the individuals. From univariate discriminant function analysis, the cubit length and foot length were selected as the best variables to discriminate sex of more than 80% (84% males and 76% females) 77% (80% males and 75% females) Uttarkashi individuals, respectively. Although the hand length was statistically different in two sexes; it was found to be a poor sex estimator than the foot length (with higher overlapped foot-length values in two sexes). The head length, mouth breadth, ear length, nose length and facial heights were found to be the poor sex estimators Uttarkashi individuals. This may be due to slight variations in the shape and size of these body segments in two sexes, thus majority of them falling in the overlapping zone. About 86% subjects (88.5% males and 87.2% females) could be classified to their correct sex category from all lineal measurements used in multivariate discriminant function analysis. The accuracy percentages achieved in present study were comparable to results of previous studies conducted for sex determination from the hand, foot or facial measurements. The climatic and nutritional factors may be responsible for differences in anthropometric measurements of Uttarkashi individuals vis-à-vis their neighbours of plain geographic areas. Multivariate DFA was found a better statistical tool for sex determination than the univariate discriminant function analysis like previous studies. Thus, the simultaneous use of multiple variables in discriminant function analysis is considered more useful for sex determination in forensic anthropology. The anthropometric variables measured between two cartilaginous landmarks like that on nose, ear and mouth were not found useful in forensic anthropological sex estimations. Present study results can have practically applications in forensic case studies, especially when dismembered body parts are found scattered at the mass causality disaster site or the crime/terrorist massacre scene. Anthropologists are expert in articulation and identification of such body dismember body parts from their preliminary morphological examinations and then from anthropometric or molecular examinations. Present study findings may also be considered as an addendum to the existing forensic anthropological data available for diverse Indian population groups.

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