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SEX DETERMINATION FROM DISCRIMINANT FUNCTION ANALYSIS OF CEPHALOMETRIC MEASUREMENTS OF BROKPAS AND PURIGPAS OF LADAKH (UT): A FORENSIC ANTHROPOLOGICAL STUDY

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Abstract: Forensic anthropology involves diverse applications of anthropological knowledge to medico-legal problems like human identification based on sex determination, age estimation, stature reconstruction and deciphering ancestry of unknown living individuals or skeletal remains. Sex can be determined by using different body parts such as extremities (legs and arms) parameters, head, face, clavicle, and others parameters. In present cross-sectional study, cephalometric dimensions of 800 Ladakhi subjects (431 males and 369 females) of Purigpas and Brokpas ancestry were taken. Descriptive statistics of cumulative cephalometrics in two sexes revealed that all the measurements were significantly larger in males than the females ($p<0.001$). Statistically significant sex differences were found in the various anthropometric, cephalometric and morphological features of Brokpas and Purigpas of Kargil (Ladakh, UT). Univariate discriminant function analysis found head length as the best cephalofacial variable to estimate sex of 73.4% individuals; followed by physiognomic facial length to estimate sex of 71% subjects. From multivariate discriminant function analysis, the physiological facial length, head length, nasal breadth, head circumference, nasal height, bizygomatic breadth, length of right ear and left ear breadth were selected as the best variables to correctly classify sex of 83.8% individuals to their category (81.9% males and 85.9% females). The present study results are the only cephalometric standards which have been suggested for Purigpas and Brokpas of Ladakh (Jammu and Kashmir) which can be used for medico-legal sex determination of unknown individuals of studied population.

Key words: Forensic anthropology, cephalometrics, sex determination, Kargil, Brokpas and Purigpas, identification.

INTRODUCTION

Identification of incomplete or damaged unknown human remains is one of the challenging tasks for the forensic anthropologists involved in such pursuits [1]. Nowadays, the entire world is experiencing mass-level catastrophes due to certain natural or manmade calamities like earthquakes, tsunamis, traffic accidents, fires, building-collapses or ill-minded human intentions like terrorism and geopolitical war scenarios. The identification of human remains retrieved from such contexts is a priority for forensic experts in identifying victims based on their sex, age-at-death, stature, ancestry and sign of any trauma or pathology [2-3]. Recent additions in the technical armamentarium of forensic anthropology has facilitated the application of anthropological knowledge to medico-legal investigations. Different molecular and chemical approaches like stable isotope and portable kit-based DNA analyses have remarkably helped in identification of migration-related undocumented border-crossers and their geographical origins [4-5]. Facial imaging and facial approximation techniques have helped in recognition and identification of the missing or suspect persons [6]. However, the tradition forensic anthropological methods still have an edge over the advanced identification methods as they are quick, cost effective and less time consuming [7-8].

Sex determination is the crucial marker of biological identity of unknown skeletal remains found in forensic or bioarchaeological contexts as it just halves the task of a forensic anthropologist involved in their biological profiling efforts. Accurate sex determination is essential for estimation of age and reconstruction of stature and ancestry of unknown human remains. Generally, there are two approaches to determine sex; morphological method based sexually dimorphic differences in human physical or anatomical features

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specifically confined to two sexes like roughness of skull, pubic angle of pelvic bone, shape of eye orbit, size and angulations of femur, shape and size of sacrum, prominence of nuchal ridges, mastoid process and supra orbital ridge in human skull [9]. Another approach is to quantify metric differences in human physical features and body dimensions based on multiple anthropometric measurements and statistical analyses. The discriminant function analysis is one of statistical tools/model to discriminate among the best variables for sex determination, with expressions of certain probabilities and accuracies [10-11].

Studies have revealed that sex can be determined by using different body parts such as dimensions of extremities, head, face, clavicle, pelvis, shoulders, and some other parameters. Different body dimensions are differently suitable for metric sex determination accuracies and reliability which vary among different population groups as body dimensions and size get influenced variably by the genetic, nutritional and environmental factors [12]; these factors impact the skeletal growth and development of the individuals leading to variations in rates/degrees of sexual dimorphism. Thus, population specific sex determination standards are needed for different ethnic groups of diverse geographical regions.

Indian population is a heterogeneous which arbitrarily clustered into different groups based on different morphological, serological and genetic features [13-14]. The inhabitants of each population cluster are expected to have a different body physique and composition, morphological and genetic features due to different nutritional and environmental conditions. The studied population of Brokpas and Purigpas (Kargil, Ladakh) presents a distinctly separate group as these two tribal groups present a different combination of morphological facial features and trace their ancestry from two different regions i.e., the Brokpas are believed to be the descendants of Aryans coming from West Asia and, the Purigpa trace their origin to Tibeto-Mongoloids. Both tribal groups had inhabited their present geographical territory since last many generations and they are exposed to comparatively harsh environmental, nutritional and climatic conditions compared to their ancestral population groups as well as the other mainland Indian population clusters. As present study individuals are exposed to quite different environmental, genetic and climatic conditions than their neighbouring population groups, so they are expected to have distinct bodily features and proportions/dimensions, morphological facial features and behavioural adjustments. Various studies have reported wide variations in cephalometric features of two sexes among different Indian population groups [3, 15-20]; but no such study was accessible in the literature to report such differences in cephalometric features of Kargil individuals; also, no population specific discriminant function equations have been suggested for the target population groups of Kargil. Present study was formulated to study sexual differences in the cephalometric features of Brokpas and Purigpas and to develop statistical equation for sex and stature estimation of unknown individuals whose remains are found in forensic anthropological and bio-archaeological context.

MATERIAL AND METHODS

Nineteen cephalometric measurements were recorded on head and face of 800 adult individuals (431 males and 369 females) belonging to the Brokpa and Purigpa tribes of Kargil (Ladakh) comprised the sample size of present study. The subjects having any head or facial deformity were ignored for taking measurements to avoid possible inconsistencies in the results. Data were collected from the 'Suru' valley and 'Batalik' sector of Ladakh region using convenient and snow ball sampling methods (Figs 1, 2). The subjects more than 25 years of age were considered for cephalometric analysis, and majority of present study subjects belonged to the age-group of 30-50 years. A pre-defined proforma of cephalometric measurements was used to record the measurements on the subjects of this study. A well-informed written consent was obtained from each subject before taking measurements by informing them about the aims, objectives and purpose of the study. The standard anthropometric techniques and instruments were used for taking cephalofacial measurements when the subject head was in Frankfurt Horizontal (FH) plane [21-23] i.e. tragion and orbitale lying in the same plane. Ethical clearance was obtained from Panjab University Institutional Ethics Committee (PUIEC) vide letter no. PUIEC/2017/66/R/06/02 dated: 21/02/2018 to conduct this study, and also "No Objection Certificate" (NOC) was obtained from the Directorate of Tribal Affairs, Government of Jammu and Kashmir, vide letter no: DTA/ESTT/2016/2043, Dated: 27/2/2017 and the District Magistrate, Kargil (Ladakh, UT) vide letter no: DMK/JC-Misc./2016, Dated: 03/08/2016

Statistical descriptive were calculated and discriminant function analyses (DFA) were done using IBM SPSS Statistics software version 21.0 [24]. Skewness

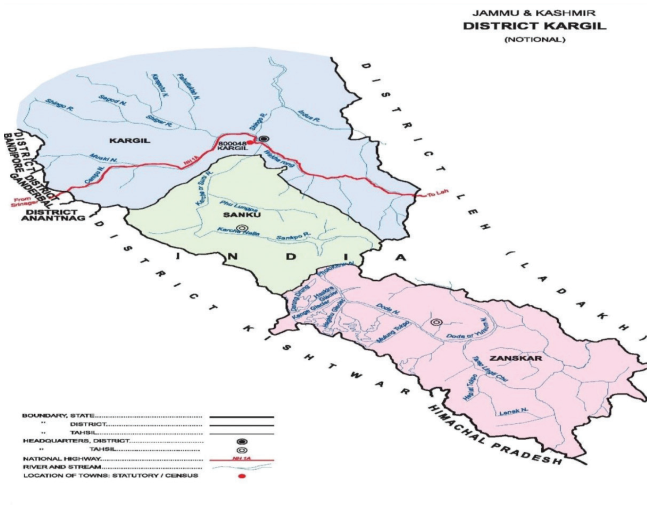

Figure 1. Geographical boundaries of the study area.

Figure 2. Picturesque terrain of the study area from where data was collected for present study.

and kurtosis were estimated to see whether the data is normally and symmetrically distributed. Variance analysis was run to see how much the population data is dispersed form the mean values. Student's independent 't'-test was applied to compare means of different variables in two sexes. The index of sexual dimorphism (ID) was calculated for each variable as per the formula proposed by Akhilaghi et al. [25]. Since discriminant functions are population-specific [26-27], both univariate and multivariate analyses were carried out to suggest the sex estimation accuracy of individual variable or different combinations of various cephalofacial measurements.

Multivariate discriminant function analysis minimizes overlap for several traits at a time by seeking a linear combination of weight variables that maximizes the between-groups variance relative to the within group variance. So, discriminant function analysis offers a straightforward statistical basis for deciding on the basis of multiple measurements, whether an individual is more likely to be a member of one or another of two well defined groups: males or females. Discriminant function analysis is a form of multivariate analysis which is used to determine which continuous variables or subjects discriminate between two or more different naturally occurring groups and also

Table 1. Descriptive analysis of Cephalometrics and anthropometrics of both Brokpa and Purigpa populations

Measurements	Males (N=431)						Females (N=369)						D	T-test	P–value
	Mean ±S.D	Range	Variance	SEE	Skewness	Kurtosis	Mean ±S.D	Range	Variance	SEE	Skewness	Kurtosis			
HL	19.25±0.82	8.00	0.86	0.06	-2.05	10.14	18.41±0.76	6.80	0.77	0.04	-0.61	2.44	0.84	14.886	.0001**
HB	14.70±0.75	7.50	0.60	0.05	-0.82	6.05	14.44±0.78	7.40	0.66	0.03	0.84	3.90	0.26	4.797	.0001**
FD	12.41±0.77	6.60	0.68	0.06	2.07	9.76	11.99±0.79	9.90	0.80	0.04	-0.41	5.44	0.42	7.667	.0001**
BZB	12.85±0.85	10.50	0.92	0.06	-2.70	21.05	12.17±0.82	6.00	0.88	0.04	-0.27	0.26	0.68	11.484	.0001**
BGD	11.29±0.81	10.60	0.71	0.06	-3.47	32.89	10.80±0.89	9.80	0.98	0.04	0.79	4.82	0.49	8.225	.0001**
NH	5.35±0.42	2.20	0.16	0.03	0.02	0.25	4.98±0.49	4.30	0.26	0.02	0.02	1.09	0.33	11.560	.0001**
NB	3.51±0.41	2.40	-0.16	0.03	-0.16	0.86	3.21±0.34	3.90	0.15	0.02	0.23	3.11	0.30	11.120	.0001**
ND	2.35±1.71	5.60	2.92	0.11	-0.35	-1.63	2.19±1.60	5.20	1.90	0.06	1.38	0.30	0.16	1.367	.172
MB	5.14±0.53	3.00	0.23	0.03	0.43	1.09	4.92±0.50	4.50	0.28	0.02	-0.43	1.74	0.32	5.966	.0001**
LEL	6.23±0.53	3.80	0.29	0.04	0.55	1.88	5.87±0.47	4.30	0.24	0.02	-0.26	1.71	0.36	10.117	.0001**
LEB	3.20±0.33	2.80	0.10	0.02	1.12	6.57	3.02±0.30	3.80	0.11	0.01	0.68	8.51	0.18	7.960	.0001**
REL	6.26±0.50	3.00	0.26	0.03	0.28	0.20	5.88±0.43	4.60	0.23	0.02	-0.19	2.51	0.38	11.142	.0001**
REB	3.22±0.33	1.80	0.10	0.02	-0.56	0.89	3.04±0.30	2.00	0.09	0.01	-0.43	1.13	0.18	8.015	.0001**
PFL	18.04±0.98	4.60	0.90	0.06	-0.24	-0.19	16.98±0.86	6.50	1.11	0.04	0.09	0.10	1.96	16.083	.0001**
MFL	11.31±0.87	4.60	0.77	0.06	-0.58	0.38	10.72±0.76	6.00	0.74	0.04	0.51	1.19	0.59	10.053	.0001**
PSFL	7.48±0.58	3.50	0.33	0.04	0.08	0.33	7.04±0.58	5.20	0.40	0.03	0.30	0.90	0.44	10.577	.0001**
MSFL	6.28±0.53	3.70	0.30	0.04	0.79	1.64	5.91±0.47	3.60	0.27	0.02	0.37	0.65	0.37	10.287	.0001**
EOB	11.24±0.60	3.40	0.38	0.04	-0.20	0.19	10.85±0.56	4.80	0.32	0.02	0.01	1.14	0.46	9.252	.0001**
HC	56.16±0.73	4.50	0.52	0.05	0.04	-0.01	55.50±0.74	5.00	0.54	0.03	0.24	0.11	0.66	4.844	.0001**

for classifying cases into different groups with a better than chance accuracy. The independent variables act as the predictors or discriminating variables whereas the dependent variables as the grouping variable or criterion variable

RESULTS

Descriptive statistics for cephalometric measurements of Kargil (combinedly for both Brokpas and Purigpas) males and females revealed that all the measurements were significantly higher in males than the females ($p<0.001$) as shown in Table 1. All the variables showed almost near to zero skewness which indicates that data was symmetric and normally distributed except for head length, frontal diameter, bizygomatic breadth, bi-gonial diameter and left ear breadth in Brokpas and only nasal depth in the Purigpas. Height showed highest variance among individuals of both the tribes studied in this study. It was found that all the variables exhibited statistically significant sexual differences ($P<0.001$). The highest t-score value was showed by head length (14.88), nasal height (11.56), bizygomatic breadth (11.48), nasal breadth (11.12) and left ear breadth (11.14).

Maximum sexual differences were noticed for physiognomic facial length (19.25±0.82 cms in males and 18.41±0.76cms in females), bizygomatic breadth (18.24±0.78 cms in males and 16.98±0.86 cms in females) and head circumference, and these variables also displayed maximum standard deviation. The physiognomic superior facial length, morphological facial length, and morphological superior facial length were also larger in males than the females. Head breadth, nasal breadth, bizygomatic breadth, and bigonial diameter and external orbital breadth were significantly narrower in females of both Brokpa and Purigpa as compared to their male counterpart. Ear length was also found larger in males as compared to females; though nasal depth and ear breadth did not show much significant difference two sexes among Brokpas and Purigpas of Kargil.

From univariate discriminant function analysis of individual cephalofacial variables of Brokpas, it was found that head length and morphological facial length were the best variables to correctly classify 74.5% (75.7% males and 73.0% females) and 73% (72.5% males and 74.2% females) Brokpas, respectively, and nasal depth and left ear index were found the poorest sex estimators to identify sex of about 45.4% and 49.0% subjects, respectively (Table 2). Similarly, head length, right ear length, physiognomic facial length

Table 2. Univariate discriminant function analysis (DFA) of cephalometric and anthropometric measurements of Brokpas

Variables	Wilk's Lambda	F-ratio	CDFC	GC		SP	FDFS		Accuracy % from FDA			
				M	F		M	F	M	F	SB	O
HL	0.794	102.999	2.775const-22.121	0.454	-0.567	-0.056	26.515-255.527	25.316-232.996	75.7	73.0	2.7	74.5
HB	0.981	7.707	1.216const-17.784	0.294	-0.155	0.139	21.774-161.053	21.434-156.090	54.1	71.3	-17.2	61.81
FD	0.901	43.748	1.230const-14.784	0.296	-0.369	-0.036	18.546-114.371	17.728-104.559	69.4	59.6	9.8	65.0
BZB	0.853	68.360	1.165const-14.294	0.370	-0.462	0.185	17.087-108.208	16.117-96.356	70.7	69.1	1.6	70.0
BGD	0.934	27.896	1.132const-12.132	0.236	-0.295	0.118	14.001-77.182	13.400-70.751	65.3	65.7	-0.4	65.5
NH	0.844	73.496	2.356const-12.163	0.384	-0.479	-0.047	29.557-79.399	27.525-68.950	68.9	70.2	-1.3	69.5
NB	0.840	75.881	2.934const-10.209	0.390	-0.486	-0.048	31.101-56.864	28.529-47.959	70.3	64.6	5.7	67.8
ND	0.999	0.319	0.617const-2.744	0.025	-0.032	-0.003	1.709-4.526	1.674-4.371	60.4	34.8	25.6	49.0
MB	0.969	12.529	2.281const-11.661	0.158	-0.198	-0.02	16.957-70.538	26.144-66.392	52.7	60.1	-7.4	56.0
LEL	0.894	47.093	1.924const-11.981	0.307	-0.383	-0.038	23.644-76.169	22.316-67.953	59.0	63.5	-4.5	61.0
LEB	0.910	39.327	3.313const-10.681	0.281	-0.350	-0.034	36.310-60.768	34.220-54.051	52.3	69.1	-16.8	59.8
REL	0.894	47.210	2.077const-12.925	0.308	-0.384	0.038	27.482-88.247	26.047-79.338	55.9	64.6	-8.7	59.8
REB	0.894	47.210	3.327const-10.477	0.308	-0.384	0.038	34.910-58.845	32.672-51.629	61.7	66.3	-4.6	63.3
PFL	0.707	165.175	1.095const-19.162	0.575	-0.718	-0.071	21.622-195.483	20.205-170.797	72.5	74.2	-1.7	73.3
MFL	0.914	37.652	1.179const-12.937	0.275	-0.343	-0.034	15.557-87.961	14.849-79.996	72.5	61.8	10.7	67.8
PSFL	0.868	60.480	1.797const-12.923	0.348	-0.434	-0.043	23.851-88.754	22.445-78.677	65.3	69.1	-3.8	67.0
MSFL	0.854	67.886	1.982const-12.025	0.369	-0.460	-0.045	24.570-77.495	22.927-67.566	58.6	68.5	-9.9	63.0
EOB	0.888	50.278	1.687const-18.894	0.317	-0.396	-0.03	32.418-185.232	31.214-171.781	66.2	55.7	10.5	66.0
HC	0.932	29.182	1.372const-30.187	0.242	-0.302	-0.03	41.736-463.664	40.991-447.274	75.2	48.3	26.9	63.3
LEI	1.000	0.004	0.203const-10.544	0.003	-0.004	-0.000	2.140-56.313	2.139-56.244	43.2	43.3	-0.1	43.3
REI	0.996	1.741	0.206const-10.717	0.059	-0.074	-0.007	2.215-58.756	2.188-57.335	55.0	52.2	2.8	53.8

CDFC= Canonical discriminant function coefficient; GC= Group Centroids; SP= Sectioning point; FDFS= Fisher's discriminant scores; M= Male; F= Female; O= Overall accuracy; SB= Sex Bias.

Table 3. Univariate discriminant function analysis (DFA) of cephalometric and anthropometric measurements of Purigpas

Varia-bles	Wilk's Lambda	F-ratio	CDFC	GC		SP	FDFS		Accuracy % from FDA			
				M	F		M	F	M	F	SB	O
HL	0.776	115.016	1.286const24.267	0.513	-0.561	-0.048	31.865-307.705	30.485-281.705	75.1	70.7	4.4	73.0
HB	0.967	13.459	1.300const-18.884	0.175	-0.192	-0.008	24.774-182.328	24.297-175.395	56.9	61.8	-4.9	59.3
FD	0.950	20.808	1.209const-15.011	0.218	-0.239	-0.010	18.416-116.652	17.864-109.802	55.5	55.5	0.0	55.5
BZB	0.859	65.095	1.221const-15.621	0.386	-0.422	-0.036	19.540-128.805	18.554-116.204	72.7	57.1	15.6	65.3
BGD	0.912	38.345	1.208const-13.796	0.296	-0.324	-0.014	17.028-99.983	16.279-91.440	64.6	62.3	2.3	63.5
NH	0.859	65.418	2.065const-10.720	0.387	-0.423	-0.018	22.934-62.369	21.262-53.704	72.7	66.0	6.7	69.5
NB	0.870	59.517	2.535const-8.253	0.369	-0.404	-0.017	21.858-37.862	19.900-31.501	61.7	69.6	-7.9	65.5
ND	0.972	11.493	3.047const-6.376	0.162	-0.117	0.022	19.922-22.069	18.888-19.908	65.6	57.1	8.5	61.5
MB	0.943	23.919	1.746const-8.658	0.234	-0.256	-0.011	15.528-40.226	14.673-35.993	59.8	55.0	4.8	57.5
LEL	0.869	59.976	2.206const-13.011	0.370	-0.405	-0.017	29.518-90.214	27.808-80.142	69.9	66.0	3.9	68.0
LEB	0.938	26.369	3.015const-9.074	0.245	-0.269	-0.012	28.097-44.116	26.547-39.458	52.2	69.1	-16.9	60.3
REL	0.826	83.584	2.274const-13.513	0.437	-0.478	-0.041	31.721-97.997	29.640-85.649	73.2	68.6	4.6	71.6
REB	0.948	21.973	3.394const-10.279	0.224	-0.245	-0.015	35.651-55.850	34.058-51.032	56.9	64.4	-7.5	60.5
PFL	0.795	102.450	1.077const-18.973	0.484	-0.529	-0.022	20.957-189.969	19.866-170.770	69.9	71.2	-1.3	70.5
MFL	0.848	71.171	1.271const-14.099	0.403	-0.441	-0.019	18.425-105.846	17.352-93.956	62.2	70.2	-8.0	66.0
PSFL	0.871	59.087	1.698const-12.502	0.367	-0.402	-0.017	21.850-83.503	20.543-73.897	65.6	70.2	-4.6	67.8
MSFL	0.909	39.865	1.993const-12.266	0.302	-0.330	-0.014	25.043-79.663	23.784-71.920	60.8	67.0	-6.2	63.8
EOB	0.912	38.583	1.828const-19.959	0.297	-0.325	-0.014	37.018-205.842	35.882-193.440	58.9	61.3	-2.4	60.0
HC	0.994	2.342	1.372const-30.146	0.073	-0.080	-0.003	41.468-457.283	41.258-452.666	66.0	39.8	26.2	53.5
LEI	1.00	0.008	0.153const-7.821	0.004	-0.005	-0.00	1.194-31.308	1.193-31.239	43.5	49.2	-5.7	46.3
REI	0.993	2.645	0.168const-8.600	-.078	0.085	-0.081	1.431-37.012	1.459-38.412	56.5	55.0	1.5	55.8

CDFC= Canonical discriminant function coefficient; GC= Group Centroid; SP= Sectioning point; FDFS= Fisher's discriminant scores; M= Male; F= Female; O= Overall accuracy; SB= Sex Bias.

Table 4. Univariate discriminant function analysis (DFA) of cephalometric and anthropometric measurements of Brokpas and Purigpas taken together

Varia-bles	Wilk's Lambda	F-ratio	CDFC	GC		SP	FDFS		Accuracy % from FDA			
				M	F		M	F	M	F	SB	O
HL	0.787	216.198	1.227const-0.562	0.481	-0.562	-0.040	28.972-279.478	27.693-225.397	74.7	71.8	2.9	73.4
HB	0.974	21.045	1.255const-18.296	0.150	-0.175	-0.012	23.152-170.828	22.743-164.879	58.7	63.4	-4.7	60.9
FD	0.935	55.229	1.183const-14.452	0.243	-0.284	-0.020	17.287-108.673	16.763-101.066	59.6	62.1	-2.5	60.8
BZB	0.875	106.901	1.133const-14.203	0.350	-0.409	-0.029	16.492-106.581	15.632-95.826	66.6	67.8	-1.2	67.1
BGD	0.940	50.655	1.079const-11.939	0.233	-0.272	-0.019	13.131-74.774	12.587-68.757	58.2	66.4	-8.2	62.0
NH	0.854	136.912	2.196const-11.317	0.383	-0.447	-0.032	25.816-69.766	23.993-60.357	70.8	68.0	2.8	69.5
NB	0.861	128.851	2.608const-8.783	0.371	-0.434	-0.031	23.877-42.595	21.777-35.549	65.2	65.6	-0.4	65.4
ND	0.997	2.310	0.604const-1.973	0.050	-0.058	-0.475	1.221-2.739	1.156-2.527	32.3	68.3	-36	48.9
MB	0.955	37.317	1.940const-9.766	0.200	-0.233	-0.016	19.330-50.354	18.489-46.130	54.3	58.3	-4	56.1
LEL	0.887	101.166	1.952const-11.832	0.329	-0.384	-0.027	23.735-74.641	22.342-66.220	60.3	66.7	-6.4	63.3
LEB	0.927	62.652	2.998const-9.344	0.259	-0.302	-0.021	28.789-46.802	27.106-41.569	57.5	70.5	-13	63.5
REL	0.867	122.350	2.083const-12.671	0.362	-0.423	-0.030	27.147-85.621	25.513-75.704	66.1	67.8	-1.7	66.9
REB	0.925	65.106	3.139const-9.832	0.264	-0.308	-0.022	31.687-51.654	29.891-46.040	57.5	66.7	-9.2	61.8
PFL	0.755	285.659	1.081const-18.982	0.526	-0.615	-0.44	21.096-190.977	19.862-169.375	69.4	74.8	-5.4	71.9
MFL	0.886	102.577	1.218const-13.439	0.331	-0.387	-0.028	16.771-95.503	15.896-85.870	63.8	71.5	-7.7	67.4
PSFL	0.875	113.526	1.725const-12.549	0.349	-0.407	-0.029	22.243-83.872	20.940-74.411	64.5	70.5	-6	67.3
MSFL	0.886	103.038	1.978const-12.084	0.332	-0.388	-0.028	24.552-77.767	23.128-69.088	63.3	65.9	-2.6	64.5
EOB	0.900	88.296	1.709const-18.903	0.307	-0.359	-0.026	32.835-185.210	31.696-172.629	61.7	65.9	-4.2	63.6
HC	0.971	24.019	1.367const-30.054	0.160	-0.187	-0.013	41.297-457.148	40.822-446.706	70.8	43.9	26.9	58.4
LEI	1.000	0.027	0.172const-8.896	0.005	-0.006	-0.000	1.534-40.308	1.532-40.204	47.8	49.9	-2.1	48.8
REI	1.000	0.122	0.183const-9.455	-.011	0.013	-0.012	1.728-45.288	1.733-45.523	52.7	50.7	2	51.8

CDFC= Canonical discriminant function coefficient; GC= Group Centroids; SP= Sectioning point; FDFS= Fisher's discriminant scores; M= Male; F= Female; O= Overall accuracy; SB= Sex Bias.

and nasal length were selected as the best univariate parameters to correctly classify sex more than 70% Purigpas to their sex category, and left ear index was found to be the poorest parameter for sex estimator in Purigpas; identifying sex of about 46% subjects only (Table 3). Univariate DFA results of different cephalofacial and anthropometric measurements in two sexes of both Brokpas and Purigpas taken together (as a Ladakhi population) have been presented in Table 4. Among different variables considered in this study, only head length, physiognomic facial length, nasal height, morphological facial length and morphological superior facial length were found to be the best univariate parameters to correctly classify sex of more than 65% Ladakhi individuals of the combined population. The sex estimation accuracy from head length was calculated out to be 73.4% (74.7% males and 71.8% females); followed by physiological facial length 71.9% (69.4% males and 74.8% females); nasal height 69.5% (70.8% males and 68.0%); morphological facial length 67.4% (63.8% males and 71.5% females); and morphological superior facial length 67.1% (66.6% males and 67.8% females), respectively. The sex bias in accuracy percentages varied from -0.4% (nasal breadth) to -36% (nasal diameter) towards females and 2% (right ear length) to 26.9% (head circumference) towards males. Though percentage of correctly classified individuals increased for two sexes, the females were comparatively better classified than the males when over-all accuracy percentages were considered. Left ear index was found as the poorest sex estimator in the combined population which could identify sex of 48.8% subjects only, followed by the nasal depth to identify sex of 48.9% individuals to their category.

From multivariate DFA of all the parameters in Brokpas, 82.3% individuals (81.1% males and 83.7% females) were classified to their sex category with sex bias of (-2.3%) towards females. Likewise, 82.4% Purigpas (80.9% males and 84.3% females) were correctly classified from multivariate DFA of all the considered variables (Table 5 and 6). Thus, the individuals of both the tribes were almost equally classified from multivariate DFA of various cephalofacial variables. When all the cephalofacial measurements of two tribes were considered together in multivariate DFA (Table 7), it was found that among all the cephalofacial variables (Function-1), the parameters of physiological facial length, head length, nasal breadth, head circumference, nasal height, bi-zygomatic breadth, right and left ear lengths were selected as the best ones to correctly classify 83.8% individuals (81.9% males and 85.9% females) to their sex category with sex bias of -4% towards the females; with sectioning point averaged to -0.069 from male (0.825) and females (-0.963) group centroids. The negative sign indicates that females were slightly better classified to their correct sex category than the males in the combined sample of Brokpas and Purigpas. In Function-II, only head and face variables was considered in multivariate DFA which found that the variables of physiological facial length, head length, bi-zygomatic breadth, external orbital breadth and morphological superior facial length were selected to correctly classify 79.9% individuals (80.3% males and 79.4% females) to their sex category with a sex bias of 0.9% towards males; thus indicating that the males were better indentified to their the biological sex category than the females. Only nasal parameters were considered in MDFA (Function-III) wherein 70.6% individuals (72.2% males and 68.8% females) were identified to their category from the selected variables of nasal height and nasal breadth; with a sex bias of 3.4% implying that males were more accurately classified from the nasal parameters of the Brokpas and Purigpas taken together. Similarly, 65.0% individuals (62.4% males and 68.0% females) were classified to their category from ear length and ear breadth of right ear (Function-IV); with sex bias of -5.6% implying that the females were more accurately classified to their sex category from the combined ear dimensions of both the Brokpas and Purigpas. In Function-V, only the indices like cephalic index, facial index, nasal index, and ear index were considered in multivariate DFA to find that only cephalic index (CI) was selected as the best variable to determine sex of 60.8% individuals (64.3% males and 56.6% females) with sex bias of (7.7%) towards the males. Thus, careful analysis of different multivariate DFA results revealed that the use of all cephalofacial and anthropometric measurements is a better option for sex determination of Ladakhi individuals of both the tribes (i.e., Brokpas and Purigpas). Among all the parameters, indices were the found to be the poorest sex estimator of individuals of two tribes considered combinedly.

DISCUSSIONS

Humans differ not only in their morphological features, bodily size and proportions, quantum of physical growth and development but also in their hormonal, behavioural, demographic, serological, and genetical endowments [28-29]. Anthropometry has remained a gold technique to quantify variations in human bodily dimensions to help in identification of

Table 5. Multivariate discriminant function analysis of cephalometric measurements of Brokpa (both sexes)

Variables	Selected variables (Wilk's Lambda)	CDFC	Eigen value/ conical correlation	SDFC	GC	F to remove	SP	FDFS		Accuracy % from MDFA			
								M	F	M	F	O	SB
Function I (All variables) Except HT , WT &Indices	PFL (0.592)	0.584		0.533		48.728		9.653	8.542				
	NB (0.591)	1.137		0.395		25.771		7.902	5.695				
	HL (0.564)	0.547		0.466		27.857		6.575	5.533				
	HC (0.554)	-0.585	0.900	-4.26	0.847^{M}	20.441		28.291	29.405				
	BZB (0.538)	0.262	0.688	0.225	-1.057^{F}	8.409	-0.105	4.791	4.291	81.1	83.7	82.3	-2.6
	REB (0.552)	1.137		0.351		18.916		19.576	17.412				
	NH (0.540)	0.576		0.244		10.049		8.393	5.695				
	ND (0.539)	-0.162		-0.263		9.814		-1.131	-0.823				
	Constant	-20.814						-561.510	-522.073				
Function II (Face and Head measurements only)	PFL (0.684)	0.676		0.617		55.271		8.929	7.819				
	HL (0.643)	0.606		0.516		28.724		5.535	4.541				
	BZB (0.613)	0.304	0.669	0.261	0.730^{M}	9.277		2.930	2.430				
	HC (0.618)	-0.487	0.633	-0.355	-0.911^{F}	12.144	-0.090	28.689	29.489	80.6	79.8	80.3	0.8
	MSFL (.608)	0.396		0.200		5.434		5.004	4.355				
	EOB (0.606)	0.300		0.178		4.306		15.215	14.722				
	Constant	-22.016						-573.265	-535.276				
Function III (Nose measurements only) NH, NB, ND	NH (0.840)	1.540	0.328	0.654	0.511^{M}	45.711	-0.063	26.491	24.721	70.7	75.3	72.8	-4.6
	NB (0.844)	1.960	0.497	0.668	-0.638^{F}	47.950		26.311	24.060				
	Constant	-14.768						-118.754	-101.857				
Function IV (Ear measurements only) REL, REB, LEL, LEB	REB (0.894)	1.900	0 .163	0.587	0.361^{M}	15.918	-0.044	21.818	20.829	64.0	68.5	66.0	-2.25
	REL (0.894)	1.219	0.375	0.587	-0.450^{F}	15.918		19.564	18.022				
	constant	-13.736						-102.791	-91.680				
Function V (Indices only) CI, NI, FI,EI	CI (.943)	0.211	0.061	1.000	$-.221^{M}$	24.280	-0.248	3.420	3.525	64.9	50.6	58.5	7.17
	constant	-16.422	0.240		$.275^{F}$			-131.933	-140.087				

CDFC= Canonical discriminant function coefficient; SDFC= Standardized discriminant function coefficient; GC= Group Centroids; SP= Sectioning point; FDFS= Fisher's discriminant scores; M= Male; F= Female; O= Overall accuracy; SB= Sex Bias.

mutilated and dismembered human cadavers found in forensic contexts [30-31]. It is the differences in the duration and intensity of adolescent spurts, hormonal imbalances, activity patterns, division of labour which account for degree of sexual dimorphism in two sexes [32-33].

Biological profiling of unknown human remains is one of the essential tasks of forensic anthropologists involved in identification strategies of the victims of mass disasters, war or war-related crimes, terrorist activities or epidemics. Sex, age, stature, and ancestry estimations play crucial role in establishing the identity of a missing or dead individual. Cephalometry is sub part of anthropometry which aims to take measurements on head and face of both the living individuals as well as cadavers [34]. Anthropometric sex determination using different body measurements is possible in recently dead persons or human remains in early stages of their decomposition, and such methods are used only when the application of other biometric identification methods like fingerprints becomes impossible [35]. Many researchers have used somatometric techniques of sex estimation from their body parts like lengths of extremities, hand and foot dimensions, facial and head measurements etc., either on individuals, skeletal remains or their radiographs. Various factors like ethnicity, age, gender, genetics, nutrition and environmental factors may affect the growth and development of an individual which results into differences in the body dimensions of different ethnic groups around the globe, so it becomes necessary to study various ethnic population

Table 6. Multivariate discriminant function analysis of cephalometric measurements in Purigpa (both sexes)

Variables	Selected variables (Wilk's Lambda)	CDFC	Eigen value/ conical correlation	SDFC	GC	F to remove	SP	FDFS M	FDFS F	Accuracy % from MDFA M	F	O	SB
Function I (All variables) Except HT , WT &Indices	HL(0.601)	0.671	0.835	0.522	0.871^{M}	40.266	-0.041	13.397	12.173	80.9	84.3	82.4	-3.4
	PFL(0.580)	0.413	0.675	0.384	-0.953^{F}	25.027		12.198	11.444				
	NH(0.570)	0.682		0.330		18.251		6.177	4.933				
	HC(0.596)	-0.713		-0.520		36.560		24.609	25.910				
	BZB(0.565)	0.358		0.294		14.222		7.228	6.574				
	REL(0.562	0.628		0.276		11.876		3.691	2.546				
	EOB(0.553)	0.345		0.189		5.572		17.169	16.540				
	MB(0.551)	0.291		0.167		4.511		2.046	1.514				
	Constant	-21.328						-686.571	-647.727				
Function II (Face and Head measurements only)	HL(0.678)	0.767	0.649	0.596	0.768^{M}	46.524	-0.036	13.136	11.902	77.0	82.7	79.8	-5.7
	PFL(0.649)	0.480	0.627	0.445	-0.840^{F}	27.568		11.642	10.871				
	BZB(0.628)	0.380		0.312		13.838		6.741	6.129				
	HC(0.642)	-0.602		-0.438		23.187		25.944	26.911				
	EOB(0.624)	0.526		0.288		11.589		18.163	17.317				
	PSFL(0.615)	0.339		0.200		5.299		5.446	4.901				
	Constant	-22.810						-683.542	-646.914				
Function III (Nose measurements only) NH, NB, ND	NH(0.870)	1.332	0.240	0.645	0.467^{M}	31.106	-0.022	19.262	17.960	67.5	68.1	67.8	-0.6
	NB(0.859)	1.495	0.440	0.590	-0.511^{F}	25.654		14.509	13.048				
	Constant	-11.780						-77.165	-65.671				
Function IV (Ear measurements only) REL, REB, LEL, LEB	REL(0.938)	1.974	0.238	0.868	0.465^{M}	63.799	-0.022	28.558	26.637	67.5	67.5	67.5	0
	LEB(0.826)	1.050	0.438	0.348	-0.509^{F}	9.054		20.257	19.235				
	Constant	-14.890						-119.600	-105.127				
Function V (Indices only) CI, NI, FI,EI	CI (0.950)	0.236	0.052	1.000	-0.218^{M}	20.774	-0.228	4.237	4.344	61.2	56.5	59.0	4.7
	Constant	-18.181	0.233		0.238^{F}			-162.024	-170.323				

CDFC= Canonical discriminant function coefficient; SDFC= Standardized discriminant function coefficient; GC= Group Centroids; SP= Sectioning point; FDFS= Fisher's discriminant scores; M= Male; F= Female; O= Overall accuracy; SB= Sex Bias.

Table 7. Multivariate discriminant function analysis of cephalometric measurements in Purigpa (both sexes)

Variables	Selected variables (wilk's Lambda)	CDFC	Eigen value/ conical correlation	SDFC	GC	F to remove	SP	FDFS M	FDFS F	Accuracy % from MDFA M	F	O	SB
Function I (All variables)	PFL(0.605)	0.493	0.797	0.456	0.825^{M}	69.304	-0.069	10.629	9.747	81.9	85.9	83.8	-4
	HL(0.600)	0.592	0.666	0.483	-0.963^{F}	61.738		9.525	8.466				
	NB(0.570)	0.655		0.251		19.461		-1.240	-2.411				
	HC(0.588)	-0.578		-0.423		19.461		27.597	28.631				
	NH(0.574)	0.604		0.275		44.713		6.685	5.605				
	BZB(0.578)	0.347		0.306		24.123		6.801	6.181				
	REL(0.565)	0.434		0.208		30.791		10.999	10.223				
	LEB(0.561)	0.458		0.153		12.151		8.530	7.711				
	Constant	-20.851				6.906		-600.690	-563.527				
Function II (Face and Head measurements only)	PFL(0.677)	0.583	0.627	0.540	0.732^{M}	80.287	-0.061	10.515	9.589	80.3	79.4	79.9	0.9
	HL(0.677)	0.711	0.621	0.580	-0.854^{F}	79.929		9.744	8.616				
	BZB(0.630)	0.297		0.262		19.271		5.029	4.558				
	HC(0.642)	-0.554		-0.405		35.064		26.358	27.236				
	EOB(0.633)	0.489		0.286		23.045		16.086	15.311				
	MSFL(0.620)	0.321		0.162		6.861		3.438	2.929				
	Constant	-22.578						-614.111	-578.401				
Function III (Nose measurements only) NH, NB, ND	NH(0.861)	1.441	0.274	.656	0.483^{M}	76.986	-0.041	22.511	21.001	72.2	68.8	70.6	3.4
	NB(0.854)	1.632	0.464	.626	-0.565^{F}	69.450		18.073	16.362				
	Constant	-12.954						-92.640	-79.106				
Function IV (Ear measurements only) REL, REB, LEL, LEB	REL(0.927)	1.664	0.174	.799	0.386^{M}	70.838	-0.065	22.872	21.481	62.4	68.0	65.0	-5.6
	LEB(0.867)	1.122	0.385	.374	-0.451^{F}	14.546		16.556	15.618				
	Constant	-13.616						-98.764	-87.400				
Function V (Indices only) CI, NI, FI,EI	CI(0.948)	.222	0.055	1.000	-0.216^{M}	43.763	-0.234	3.763	3.867	64.3	56.6	60.8	7.7
	Constant	-17.179	0.288		$.0253^{F}$			-144.557	-152.626				

CDFC= Canonical discriminant function coefficient; GC= Group Centroids; SP= Sectioning point; FDFS= Fisher's discriminant scores; M= Male; F= Female; O= Overall accuracy; SB= Sex Bia.

Table 8. Comparison of present study with others studies were cephalofacial variables used for univariate and multivariate discriminant function analysis

Author's	Ethnic group and sample size	Variables	Method	Accuracy % Male	Female	Overall
Shah, et al.[16]	Gujarati 901 (676M; 225F)	MFL, THH,PFH, BOB, MHL, MHB, BZB, BGB	Multivariate DFA	79.6	80.9	80.2
Mahalaksahmi and David [42]	Bengaluru 156 (76M and 80F)	HL, Ba-ANS, N-ANS, Ba-N, N-M, FsHt, Ma-SN, Ma-FH, MaHt, MaWd	Univariate FDA	-	-	73.1
Patil and Mody [41]	Maharastrian150(75M; 75F)	HL, Ba-ANS, N-ANS, Ba-N, N-M,FsHT, Ma-SN, Ma-FH, MaHt, MaWd	Univariate DFA	-	-	90
Adamu, et al. [37]	Nigerian	UFH, SUT, NW,LFW, MB, OW	Multivariate	-	-	91
Present study	Ladakhi 800(431M;369F)	PFL, NB, HL,HC, BZB, REL, LEB	Multivariate	81.9	85.9	83.4

groups [29]. Discriminant function analysis is a highly used statistical tool by forensic experts for the most reliable and accurate sex estimations [36]. Fisher's [10] multivariate discriminant function analysis is enlisted into the service of forensics as a statistical tool in order to compensate for the faint applicability of morphoscopical trait analysis, and to reduce the inter-observer errors in sexing the human remains.

In present study, univariate DFA was applied for sex estimation from various cephalofacial variables among both the Brokpas and Purigpas of Kargil. It was observed that amongst all the cephalofacial variables, the head length, physiognomic facial length, nasal height, morphological facial length and morphological superior facial length were selected as the best ones to correctly classify sex of more than 65% Brokpas and Purigpas. 73.4% individuals (74.7% males and 71.8% females) of both studied ethnic groups of Kargil were correctly classified from head length only. Physiognomic facial length could identify sex of 71.9% individuals (69.4% males and 74.8% females).

The cephalometric dimensions of Nigerian (Hausa) individuals was found reliable enough to determine sex of up to 91% individuals and upper facial height was tipped to be the best sex predictor [37]. Bigonial diameter and morphological facial height were found larger in Nigerian males than the females [38]. Racial and sexual differences in nasal ergonomics were found to be important from medicolegal, clinical, anthropological and forensic [39]. The cephalometrics on cephalograms equally important for assessing sexual dimorphism in 86 to 99% Indians [40-41]. Naikmasur et al., [3] found that 81.5% South Indians (77.8% males and 85.2% females) could be correctly identified to their sex category from their cephalometrics.

Shah et al., [16] estimated sex from discriminant function and logistic regression analysis of different cephalofacial parameters of Guajarati subjects and found that among cephalofacial parameters, the head length, head breadth, bizygomatic breadth, bigonial diameter, physiognomic facial length morphological facial length and external orbital breadth could identify sex of 76.4 to 82.7% and 67.4% to 68.4% individuals, respectively; the morphological facial length and bigonial diameter were found best sex predictors However, in the present study, the morphological facial length could correctly classify sex of 67.4% individuals, and bigonial diameter was not selected as best predictor for sex estimation in Brokpas and Purigpas. From multivariate discriminant function, correct sex estimation accuracy of about 79.9% was achieved whereas from multivariate regression analysis, about 82% individuals were correctly classified among the Gujarati (Indian) individuals. The upper facial height was found as the best linear cephalometric dimension to accurately classify sex of 76.2% Nigerian (Hausa) individuals [37], and this accuracy rate was higher than the morphological facial length of present study which could classify only 67.5% individuals (63.8% males and 71.5% females). However, when all linear dimensions (upper facial height, special upper facial height, nasal width, lower facial width, mouth width and orbital width) were pooled together, 91% Nigerians could be correctly classified. Divankar et al., [15] reported that cephalometric features exhibit significant sexual dimorphism and cent-percent individuals can be correctly identified by discriminant function analysis, though only 81.9% present study individuals could be sexed correctly from eleven cephalometric parameters considered. Binnal and Devi, [40] concluded that sexual dimorphism in craniofacial features is due to initial accomplishment of skeletal maturity in females than the males; no such relationship was scrutinized in present study. More than 73% Bengaluru individuals (61.5% males and 59.5% females) were correctly classified to their category from the multivariate DFA of their 10 cephalometric parameters taken on lateral cephalogram [42]; the mastoid height alone determined sex of 71.8% individuals accurately. Similarly, sex of cent percent Taiwanese was determined from their 18 cephalometric measurements taken on their tele-radiographs [43].

In conclusion, sex determination is one of the essential priorities for the medico-legal and forensic experts in the process of biological profiling in case of accidents, warfare and natural disasters when only the fragments of body parts were available. The current study has conducted for the first time among Ladakhi population of the northern most Union territory of India to test the reliability and applicability of sex determination standards developed from cephalofacial variables by using univariate and multivariate discriminant function analysis. It was revealed that multivariate discriminant function was found to be more reliable than univariate discriminant function to determine sex in the present study. The findings of the present study have significant ramifications for identification unknown, mutilated and dis-membered human cadavers. The standards so developed can be applicable for the specific population to sex determination.

Conflict of interest. There is/are no potential conflict/s of interest with anyone regarding publication of this manuscript.

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