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From Skull to Identity: Cephalometric Parameters as Predictors of Stature, Sex, and Ethnicity in Pakistan

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ABSTRACT

Background: Head anthropometric measurements are crucial for identifying unknown bodies, dismembered parts, and decomposed corpses, especially when DNA profiling is unavailable. These measurements help distinguish sex and ethnic differences, which are vital in forensic investigations. Understanding biophysical skeletal variations across ethnicities is vital for medico-legal identification. This study aimed to correlate and predict stature, sex, and ethnicity using head and face measurements in a Karachi-based population.

Methods: This cross-sectional study was conducted at the Department of Forensic Medicine &Toxicology, Ziauddin University Karachi, from January to June 2022. A total of 236 healthy Participants (126 males, 113 females), aged 20-60 years, representing various ethnic groups, were selected using non-probability consecutive sampling. Statistical analyses were done using SPSS version 24, and analyses included normality assessment, descriptive statistics, ANOVA, post hoc tests, multiple regression, and Pearson correlation to evaluate cephalometric parameters' association with stature, sex, and ethnicity in adults aged 20–60. A P-value ≤ 0.05 was considered statistically significant.

Results: Significant differences in mean stature were observed between males (170±6 cm) and females (159±6 cm) (P<0.001). Cephalometric parameters correlated with biophysical traits (P<0.05). Head circumference predicted stature (ß=0.657, P=0.022), while morphological face height predicted sex (ß=-5.704, P<0.001), stature (ß=0.187, P=0.023), and ethnicity (ß=1.336, P<0.001). Maximum head length predicted ethnicity (ß=-0.502, P=0.04) and stature (ß=0.295, P<0.001).

Conclusion: Head and face measurements offer a reliable identification method, especially in cases of incomplete bodies, aiding forensic applications in determining stature, sex, and ethnicity.

Keywords: Anthropometry, Forensic Anthropology, Body Height, Sex, Ethnicity, Pakistan.

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INTRODUCTION

Human beings are complex animals with many intraspecies differences. The variance of human characteristics may be attributed to nutritional, geographic, environmental, and genetic factors[1]. Hybridization, mutation, and natural selection also play an important role in this uniqueness. Human identification becomes necessary because of this variation since everyone possesses distinct features unique to that particular individual[2]. Personal identity is the summation of a set of three characteristics, which consist of physical, psychological, and social features unique to that person. Cephalometry is an important branch of forensic anthropometry in the field of forensic sciences, which is related to the study of morphological features and measurements of the human head[2]. Sex estimation is a key analysis that forensic anthropologists perform to establish a biological profile of individual remains. The skull is usually regarded as the most reliable indicator for sex discrimination after the pelvis[3]. Its purposes of developing biophysical profiles for deceased unknown persons are crucial in establishing identity and helping solve criminal cases.. Not only is it of immense importance in identification of the dead and archaeological samples, but its scope has also been extended to living beings' identification, trauma analysis, orthodontic reconstructive treatment planning and age determination[4,5]. Forensic Anthropology and people trained in this specialty have become an essential part and parcel in investigations of unidentified and missing persons, especially in terrorists' activities leading to mass disasters[6].

Although DNA analysis techniques are more specific for identification purposes, they are not always readily available for sample processing, the results take time, and adequate samples of DNA are required for accurate analysis[7]. Therefore, biophysical parameters are fundamental when investigating dismembered body parts to identify victims, and the ability to recreate larger identifying features from individual body parts has played a big role in missing persons cases[8]. Studies have been conducted to estimate gender, age, race, and stature by objectively examining various bones, with many researchers correlating head and facial measurements with an estimation of sex and stature[9,10]. The majority of these measurements have been used in Orthodontics and aesthetic surgeries of face[11]. If we look into South Asia, there is a paucity of such data, with only a few studies conducted in the last five years[9,12,13,14].

The objective of this study was to investigate the correlation of measurements of the head and face with the stature, sex, and ethnicity of an individual and to derive an equation for the prediction of these parameters from the measurements. This will assist forensic experts in establishing the identification of an unknown person, especially in mass disasters, from skulls.

METHODS

This Cross-sectional study was conducted from the start of January 2022 to June 2022 in the Department of Forensic Medicine & Toxicology, Ziauddin University, Karachi, Pakistan. Institutional Ethical Review Committee approval was obtained vide Reference Code 3110121MFFM. A total of 236 healthy participants comprising 123 males and 113 females in the age group of 20 to 60 years were enrolled in the study by using a non-probability consecutive sampling technique. Initially, an equal number of participants from both genders were taken, but later on, 13 females withdrew from the study. The sample size was calculated by using Sample Size Calculators for designing clinical research. By using the correlation of Stature with maximum head length as 0.21, confidence level as 95%, and power of study as 90%, the calculated sample size was found to be 234, but this study included 236 participants[9].

The Inclusion criteria consisted of healthy subjects without any craniofacial deformity, congenital deformity or any acquired deformity of the spine, extremities or head were excluded from the study. Subjects were included from different ethnic backgrounds, i.e., Punjabi, Pashtun, Balochi, Urdu speaking, Sindhi, and Chitrali, while all individuals with ages below 20 years and more than 60 years or having facial, spine, or limb deformities or with bone deformity were excluded from this study.

The height of all subjects was measured by an anthropometric rod. Stature was taken as crown-heel length with the subject standing erect and in anatomical position. Stature was measured to the accuracy of 0.1 cm. Head Circumference (mm), Morphological Face Height (mm), Maximum Head Length (mm), and Maximum Head Breadth (mm) were taken. Head Circumference (HC) was taken using an inflexible measuring tape, taking the widest way around the head. Maximum Head Length (MHL), which is the distance between the glabella and opisthocranion, and Maximum Head Breadth (MHB), which is the maximum distance between the most lateral points on the parietal bones, were measured using an outside spring-joint caliper. The Morphological Face Height (MFH), taken as the straight vertical distance between nasion to gnathion, was measured using a digital vernier caliper. A prescribed proforma was designed for recording the findings. All the measurements were taken at fixed time to eliminate diurnal variations and by one observer to avoid inter observer bias.

Statistical analysis was performed by SPSS version 24. The assumptions of normal distribution were assessed by the Shapiro Wilk test of normality which showed the stature and head length were normally distributed. Descriptive statistics was applied as mean and SD for stature, and the parametric cephalo-facial measurements and median with interquartile ranges were presented for head circumference, morphological face height, and breadth of maximum head. The frequency along with their percentages, were calculated for gender and ethnicity.

The association of cephalometric parameters with ethnic groups and gender was checked using ANOVA followed by post hoc analysis. Multiple linear regression models were employed to estimate the stature by the cephalometric parameters. The relationship pattern of stature with each parameter was assessed using Pearson correlation. The significant level was considered at P-value less than 0.05. The range, mean, Standard Deviation and Correlation coefficient, stature, Head Circumference, Morphological Face Height, Maximum Head Length, and Maximum Head Breadth were statistically analyzed. Correlation coefficient and Regression equation for predicting stature, sex, and ethnicity from head and face dimensions were derived using multiple regression analysis. The age of 20 is taken for the minimum cut-off for cephalo-facial measurements because even though growth continues after the pubertal growth spurt of facial bones, it slows considerably after 20 years and is more related to remodeling[1]. The maximum age cut-off for cephalo-facial measurements was taken as 60 due to the effects of aging and, therefore, mineral resorption in bones occurring most rapidly between the ages of 60-69 [15].

RESULTS

Table 1: Descriptive Analysis of the Parameters

Variables	Mean± SD/ Median [IQR] or Frequency (%)
Gender	
Male	123(52.1)
Female	113(47.9)
Ethnicity	
Urdu-speaking	82(34.7)
Punjabi	55(23.3)
Sindhi	41(17.4)
Pashtun	27(11.4)
Balochi	3(1.3)
Chitrali	21(8.9)
Others	7(3.0)
Age	28 [11]
20-29	140(59.3)
30-39	56(23.7)
40-49	33(14.0)
50-60	7(3.0)
Height(mm)	165.2±8.5
Head Circumference (mm)	555.9±28.6
Morphological Face Height (mm)	106.1±9.2
Maximum Head Length (mm)	178.7±7.2
Maximum Head Breadth (mm)	146.5±6.8

Out of 236 participants, 113 (48%) were females and 123(52%) were males with the mean age of 30±8 years ranging from 20 to 60 years. The majority of the people were Urdu speaking 82(34.7%) followed by Punjabi and Sindhi (23% and 17.4% respectively). The descriptive presentation of the data is given in **Table 1.**

Table 2 (a): Comparison of Mean Stature Measurement with Demographic Characteristics

Demographic Characteristics	Mean Stature Measurement (Mean± SD)	P-value
Gender		
Male	170±6	**< 0.001**
Female	159±6	
Ethnicity		
Punjabi	163.7356±8.7019	**0.001**
Sindhi	165.7146±7.9994	
Pashtun	169.5670±4.8501	
Balochi	166.4333±10.9426	
Chitrali	159.1548±4.6260	
Urdu speaking	165.7134±9.4883	
Others	168.5214±6.2330	

Table 2 (b): Post Hoc Analysis

Ethnicity		Mean Difference	P-value	95% Confidence Interval	
				Lower Bound	Upper Bound
Urdu speaking	Punjabi	1.97778	0.169	-0.8433	4.7988
	Sindhi	-0.00122	0.999	-3.0972	3.0947
	Pashtun	-3.85362*	**0.036**	-7.4450	-0.2622
	Balochi	-0.71992	0.882	-10.2343	8.7945
	Chitrali	6.55865*	**0.001**	2.6001	10.5173
Punjabi	Urdu speaking	-1.97778	0.169	-4.7988	0.8433
	Sindhi	-1.97900	0.244	-5.3187	1.3607
	Pashtun	-5.83140*	**0.003**	-9.6349	-2.0279
	Balochi	-2.69770	0.580	-12.2942	6.8988
	Chitrali	4.58087*	**0.031**	0.4289	8.7329
Sindhi	Urdu speaking	0.00122	0.999	-3.0947	3.0972
	Punjabi	1.97900	0.244	-1.3607	5.3187
	Pashtun	-3.85240	0.060	-7.8640	0.1592
	Balochi	-0.71870	0.884	-10.3996	8.9622
	Chitrali	6.55987*	**0.003**	2.2164	10.9033
Pashtun	Urdu speaking	3.85362*	**0.036**	0.2622	7.4450
	Punjabi	5.83140*	**0.003**	2.0279	9.6349
	Sindhi	3.85240	0.060	-0.1592	7.8640
	Balochi	3.13370	0.531	-6.7168	12.9842
	Chitrali	10.41228*	**< 0.001**	5.7028	15.1217
Balochi	Urdu speaking	0.71992	0.882	-8.7945	10.2343
	Punjabi	2.69770	0.580	-6.8988	12.2942
	Sindhi	0.71870	0.884	-8.9622	10.3996
	Pashtun	-3.13370	0.531	-12.9842	6.7168
	Chitrali	7.27857	0.152	-2.7117	17.2688
Chitrali	Urdu speaking	-6.55865*	**0.001**	-10.5173	-2.6001
	Punjabi	-4.58087*	**0.031**	-8.7329	-0.4289
	Sindhi	-6.55987*	**0.003**	-10.9033	-2.2164
	Pashtun	-10.41228*	**< 0.001**	-15.1217	-5.7028
	Balochi	-7.27857	0.152	-17.2688	2.7117

The mean stature measurement was compared gender-wise and showed a significant increase in males on average as compared to females 170±6 and 159±6 respectively as P-value<0.001. The ethnic group showed significant value (P-value=0.001) for the stature measurement with the highest mean value in the Pashtun community. The details of multiple comparison analyses showing significant differences are given in **Table 2**.

Table 3a: Regression analysis to estimate Stature, Sex, & Ethnicity from Cephalometric Parameters.

Parameters	R	R^2	P-value
Head Circumference	0.229	0.52	**0.006**
Morphological Face Height	0.502	0.252	**< 0.001**
Maximum Head Length	0.459	0.210	**< 0.001**
Maximum Head Breadth	0.187	0.035	**0.040**

Table 3b: Multiple Linear Regression Analysis

Parameters		Unstandardized B	Coefficients Std Error	Standardized Coefficients Beta	t	P-value	95% CI (Lower Bound)	95% CI (Upper Bound)
Head Circumference	(constant)	450.563	52.250	-	8.623	**< 0.001**	347.618	553.508
	Sex	-2.687	4.825	-0.047	-0.557	0.578	-12.194	6.820
	Ethnicity	0.304	1.072	0.018	0.284	0.777	-1.807	2.415
	Stature	0.657	0.285	0.195	2.308	**0.022**	0.096	1.218
Morphological Face Height	(constant)	80.132	15.003	-	5.341	**< 0.001**	50.572	109.691
	Sex	-5.704	1.386	-0.309	-4.117	**< 0.001**	-8.434	-2.974
	Ethnicity	1.336	0.308	0.247	4.342	**< 0.001**	0.730	1.942
	Stature	0.187	0.082	0.172	2.288	**0.023**	0.026	0.348
Maximum Head Length	(constant)	133.993	12.075	-	11.097	**< 0.001**	110.202	157.784
	Sex	-1.807	1.115	-0.125	-1.620	0.107	-4.004	0.390
	Ethnicity	-0.502	0.248	-0.119	-2.028	**0.044**	-0.990	-0.014
	Stature	0.295	0.066	0.346	4.483	**< 0.001**	0.165	0.424
Maximum Head Breadth	(constant)	114.527	12.624	-	9.072	**< 0.001**	89.656	139.399
	Sex	1.030	1.166	0.075	0.883	0.378	-1.267	3.326
	Ethnicity	0.054	0.259	0.014	0.209	0.835	-0.456	0.564
	Stature	0.183	0.069	0.228	2.668	**0.008**	0.048	0.319

Stature was estimated from the cephalometric parameters, as shown in **Table 3.**

Multiple linear regression was used to test if sex, stature, and ethnicity significantly predicted the cephalometric cephalometric parameters of Head Circumference, Morphological Face Height, Maximum Head Length, and Maximum Head Breadth.

For Head Circumference (HC), the fitted regression model was as follows:
HC = 450.563 – 2.687*sex + 0.304*ethnicity + 0.657*stature

The overall regression was statistically significant (R2=0.52, F (3,232) =4.279, P-value=0.006). The regression coefficient represents a 2.687-point decrease in the predicted value of head circumference between males and females, a 0.304 increase in ethnicity, and a 0.637 difference between stature, with Stature significantly predicting head circumference (ß=0.657, P=0.022).

For Morphological Face Height (MFH), the fitted regression model was as follows:
MFH = 80.132 -5.704*sex +1.336*ethnicity + 0.187*stature
The overall regression was statistically significant (R2=0.25, F (3,232) =25.997, P-value<0.001).
It was found that sex (ß=-5.704, P<0.001), stature (ß=0.187, P=0.023), and ethnicity (ß=1.336, P<0.001) significantly predicted morphological face height.

For Maximum Head Length (MHL), the fitted regression model was as follows:
MHL = 133.993 -1.807*sex – 0.502*ethnicity + 0.295*stature
The overall regression was statistically significant (R2=0.21, F 3,232) = 20.616, P-value<0.001).
It was found that sex did not significantly predict MHL (ß=-1.807, p=0.107), whereas ethnicity (ß=-0.502, P=0.04) and stature (ß=0.295, P<0.001) did significantly predict MHL.

For Maximum Head Breadth (MHB), the fitted regression model was as follows:

MHB = 114.527 + 1.030*sex + 0.054*ethnicity + 0.183*stature

The overall regression was statistically significant (R=0.35, F (3,232) = 2.810, P-value=0.040).

It was found that neither sex (ß=1.030, P=0.378) nor ethnicity (ß=0.054, P=0.835) were significant predictors of MHB, however, stature (ß=0.183, P=0.048) was a significant predictor.

DISCUSSION

Forensic anthropology has developed significantly over past decades in disaster victim identification.[16] Various experts agree that gender and stature predictions from peripheral long bones or digits are reliable and accurate.[17,18,19,20,21] The skull or head is often the only body part to be discovered during forensic investigations and thus can be a useful tool in determining the identity of the person. Many studies have been conducted worldwide on anthropometric measurements and their relationship with personal identification [6,16,17,] however, in Pakistan, very few studies of this kind have been published despite the presence of different sub-ethnic groups and distinct biophysical characteristics.

The determination of sex in forensic anthropology has often relied on gross anatomical differences observed on visual examination. Differences in weight, shape, size, and texture can be indicators of a particular sex. However, these methods are subjective, and results may differ due to observer bias depending on how well-versed an expert is on the nuances of skeletal sexual dimorphism. In this regard, morphometry offers a more objective method of differentiating between male and female skeletons[22,23,24]. With regards to our study, Morphological Face Height was a significant parameter in differentiating sex. This is in agreement with the findings reported in literature, which noted an 82.5% accuracy in their predictive model[25].

For stature prediction, it is worthy to note that all four parameters showed significant relationships: head circumference, morphological face height, maximum head length, and maximum head breadth– with head circumference having the greatest correlation and maximum head breadth having the least. These results correspond well with a study that observed that horizontal head circumference, maximum head height, and maximum head width give a better prediction of stature[26]. In addition, a study published regression formulae to calculate stature from various cephalometric measurements from males and females of an Indian population[27]. They also observed that total facial height, bigonial width, and physiognomic facial height (morphological face height) were good predictors of stature.

Ethnicity and race are becoming difficult characteristics to correlate[28]. The Morphological face height was the only parameter with a strong predictive value, according to our research results. One of the reasons may be that in highly cosmopolitan cities like Karachi, there is a mixing of ethnicities by intermarriages going back at least 1 or 2 generations and environmental factors affecting nutrition, health, and appearance, thus affecting the precision of ethnicity prediction. Current research has been utilizing the cranium and more so the sinuses to predict ethnicity, however, few studies have been successful in deriving race or ethnic subgroups from cephalo-facial measurements[29]. The interpretation of well-balanced faces and harmonious profiles may differ between individuals and cultures or be influenced by Eurocentric norms; all of these aspects could bias the selection of participants[30].

CONCLUSION

The results highlight that estimation of a basic biophysical profile involving sex, stature, and ethnicity of an individual using cephalo facial measurements, via multivariate analyses, can be successfully extracted for the Pakistani population when extremities are not available. These techniques can be invaluable during situations in which mass human identification is urgent and complicated and as supportive evidence to DNA analysis results.

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CONFLICT OF INTEREST

None

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ETHICAL APPROVAL

The study received ethical approval from the Ethical Review Committee, under reference number (3110121MFFM).

AUTHORS' CONTRIBUTIONS

MMF conceived the study, carried out data collection, performed statistical analysis, and drafted the manuscript. **SA** conceived the study and carried out data collection. **QH** participated in the design and coordination of the study and helped to draft the manuscript. All authors contributed to the final text and approved it.

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