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# Variability in human external ear anthropometry-Anthropological and forensic applications

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**Abstract**

The human auricle has attracted the attention of forensic scientists since a long for its unique morphological characteristics. In modern times, these unique features can be captured by CCTV cameras, which may be extremely useful during the identification process in a criminal investigation. Unique morphological characteristics such as Darwin's tubercle, shape, and size of the ear, different morphological features of the helix, tragus, lobule, etc. are frequently used in the identification and individualization process. The human ear was not only accessible for its morphological and morphometric variations, but also its existing bilateral, sex, and population differences. The present study was conducted on 140 individuals (71 males and 69 females) aged between 18 and 30 years. The data were collected from the colleges of Nahan city of Sirmaur district in Himachal Pradesh state of North India. Various anthropometric measurements were taken independently on the left and right ear of each individual with the help of a pair of sliding calipers using a standard method. These linear measurements were physiognomic ear length, physiognomic ear breadth, ear length above tragus, distance from tragus to antihelix, distance from tragus to the helix, lobule height, and lobule width. Auricular index, lobular index, and lobular ear index were calculated from the aforementioned measurements. Further, an independent t-test/ Mann Witney U test and paired sample t-test/ Wilcoxon Signed Rank test were applied for the evaluation of sex differences and bilateral differences in the human ear, respectively. For the prediction of sexual dimorphism, discriminant function analysis was applied. Physiognomic ear length, physiognomic ear breadth, ear length above tragus, distances from tragus to antihelix (left ear only), and tragus to helix exhibited significant sex differences on both sides ($p<0.05$). Significant bilateral differences ($p<0.05$) were reported for all the measurements of the ear in males except for lobule height, whereas, significant side differences ($p<0.05$) were shown for ear length above tragus, distance from tragus to helix, and lobule width among females. The discriminant function model showed 82.10% accuracy for determining sexual dimorphism. The study highlighted sexual dimorphism and bilateral differences in ear morphometry in a north Indian population and provided a database of anthropometric variables in the human ear for forensic and anthropological uses. ***Clin Ter 2021; 172 (6):531-541. doi: 10.7417/CT.2021.2374***

**Key words**: *Forensic anthropology, Human ear, Anthropometry, Bilateral differences, Sexual dimorphism*

## Introduction

The major concern of the forensic anthropologist is identification by estimating age, sex, and stature (1,2). Biometrics has played a vital role in identification. Face, fingerprints, iris, gait, ear, voice, etc., are some of the personal characteristics of humans which can be used as biometrics (3). The external ear is one of the most peculiar characteristic present on the face of an individual. Its appearance does not change with a change in facial expressions, unlike the other parts of the face, which change with changes in emotions, and thus, it possesses a relatively stable configuration. The ear is rarely affected by cosmetics and unhygienic state in comparison to several other biometric characteristics (4) however; age-related changes have been recorded by various studies (5-8). The morphological features such as the shape of the ear, the shape of the lobule, presence or absence of Darwin's tubercle, etc. make it unique and hence, it is considered as one of the significant parameters in biometrics. Human ear being relatively larger in size than other biometric features such as iris, retina, fingerprints, etc. can be easily seen from a distance or can be easily captured by the CCTV footage (9).

The variations and distinctions in various anatomical features of the external ear such as tragus, antihelix, helix, earlobe, scapha, etc. are the essential features being exploited in the identification process. The importance of ear morphology lies in the fact that it also helps in the interpretation of the ear prints encountered at the crime scene in forensic settings. Moreover, it adds to the frequency of morphological characters of ears and allows for the prediction of the features on the ear impression (9). Further, it has been extensively used in the ergonomic design of ear-related products like helmets, earphones, hearing aids, earrings, etc. (10-12).

The uniqueness of ear and ear-prints has been reported by several researchers (13,14), that are to be used in forensic examinations with caution and combination with other body characteristics. The "*Descent of Man, and Selection in Relation to Sex*" was published in 1871 by English naturalist Charles Darwin (15). He described many vestigial features of the human body in this book. One of the vestigial features

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was the auricular tubercle, commonly known as Darwin's tubercle described as nothing, but the reducing corner of the primitive ear that is presented as a thickening on the helix at the junction of the upper and middle helical border. In 1896, Alphonse Bertillon, the Chief of the Judicial Identification Service of France was the first to investigate the potential of ears in human identification (16). Alexander and Laubach (17) conducted a photogrammetric study and developed a technique that enables specified ear dimensions to be measured directly from photometric slides in a precise manner. Further, they devised regression equations for predicting various ear dimensions from ear length and ear breadth (17). Iannerelli (18) considered the ear as unique as fingerprints and explained the morphological basis for the application of the ear in ascertaining the identity of individuals (18). Previously, several studies have been conducted on the human auricle which highlighted bilateral and sex differences in the external ear (7,19-25). Alexander et al. (21) reported significant trends in sex differences and demonstrated ethnic differences that were mostly observed in Indians followed by Caucasians and Afro-Carribeans. The ear dimensions possess a probable use in the creation of an image of the human face in proportion to other facial features (21). Moreover, in an attempt to examine the ear morphology, Chattopadhayay and Bhatia (26) indicated that indices and ear morphology can help in the process of inclusion and exclusion and act as corroborative evidence in forensic examination. Additionally, the role of genetics in determining the shape and size of the external ear was also studied by Zulkifli et al. (27), who recorded strong similarity in relation to the same genetic makeup of monozygotic twins.

The present study is an attempt to detail the anthropometric variations in the ear using different measurements in a population from Himachal Pradesh in North India. The study further explored sexual dimorphism and bilateral asymmetry in different anthropometric measurements taken on the human ear.

## Materials and Methods

### *Sample*

The sample for the present study comprised 140 healthy individuals (71 males and 69 females) in the age range of 18 to 30 years (mean age 20.22±1.77 years). Thus, a total of 280 ears were examined in the present study. The primary data were collected from the students and the staff at the colleges of District Sirmaur in Himachal Pradesh State of North India. Only those, who were the original natives of the area, were enrolled in the study. The nature of the research work was explained to the participating volunteers, and written consent was taken from each participant before initiating the study. The general information and the basic demographic profile of the participants were obtained with the help of a questionnaire. The subjects with a previous history of any developmental defects of the pinna, abnormalities such as congenital anomalies, ear disease, ear trauma, maxillofacial deformity, or ear surgery were excluded. The effect of aging always exists on the facial proportions; therefore, adult participants of similar ages were selected to minimize age-related variations in the auricle morphology. Furthermore, this research is a part of a larger project (28,29).

### *Anthropometric measurements of the ear*

Before marking the landmarks on the human ear and taking various measurements on the human ear, it is essential to know its various morphological features. These morphological features have been depicted in a photograph of the human ear (Fig. 1). The participants were asked to sit in an

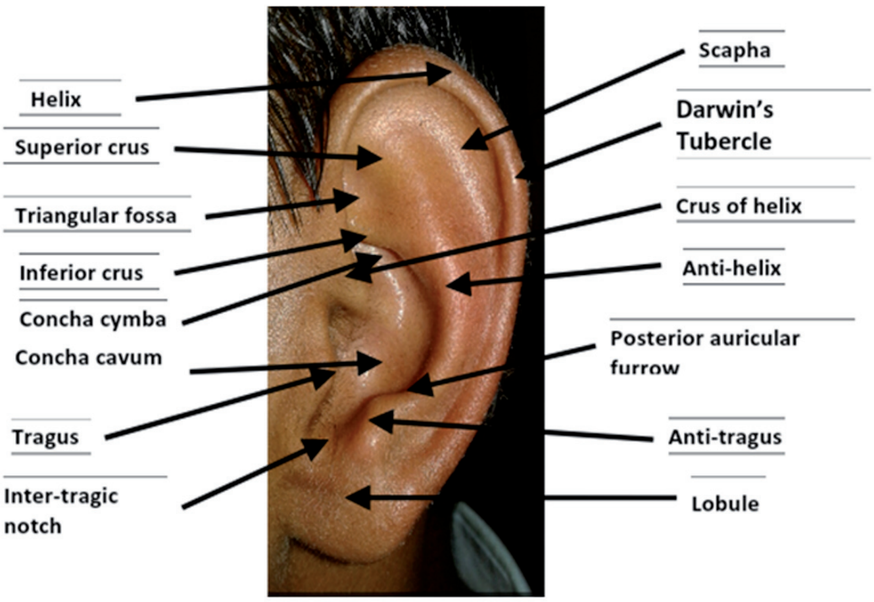


Fig. 1. Depiction of various features of the human external ear

upright relaxed position with their head in the Frankfurt Horizontal plane. The anthropometric landmarks were then identified on the subjects with careful inspection, and the same was marked with a colored pencil. The standardized anthropometric measurements of the ear were taken with precision and accuracy using sliding calipers.

Seven measurements of the human auricle were taken and recorded by one investigator (DR) on both ears to evaluate the bilateral differences in the study sample. For each ear measurement, the concurrent reading was obtained, and the mean values were calculated. The landmarks used and various measurements were taken in the study were depicted in Figure 2 and Table 1. The linear measurements included physiognomic ear length, physiognomic ear breadth, ear length above tragus, distance from tragus to antihelix, distance from tragus to the helix, lobule height, and lobule width. All the measurements included in the present study were shown (Figure 2) and described as follows (Table 1):

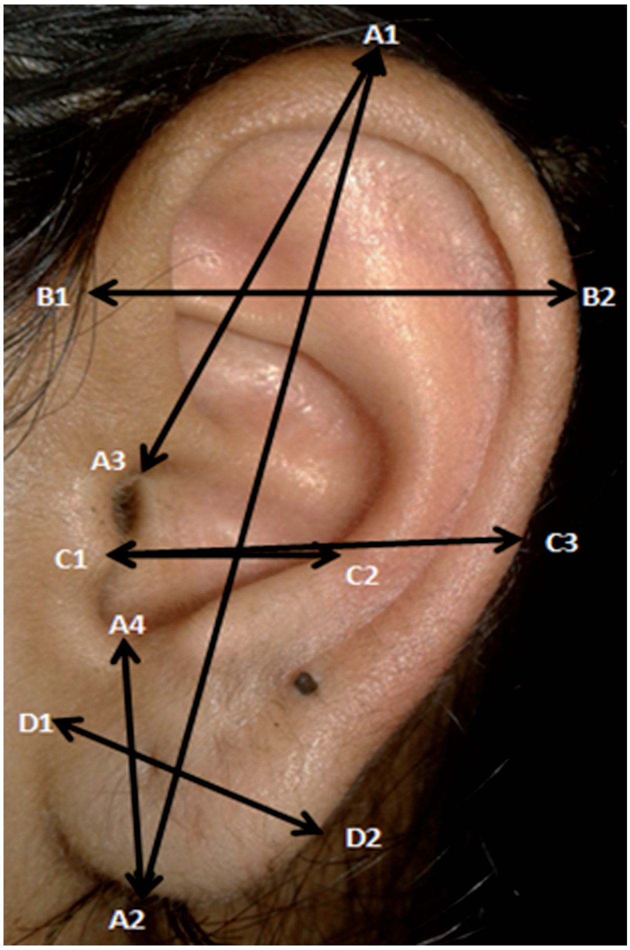


Fig. 2. Various anthropometric measurements on the human ear. (A1-A2- Physiognomic ear length; A1-A3- Ear length above tragus; A4-A2- Lobular length; B1-B2- Physiognomic ear breadth; C1-C2- Distance from tragus to anti helix; C1-C3- Distance from tragus to helix; D1-D2- lobular width)

*Table 1. Anthropometric measurements and their definitions used in the study.*

| Measurements | Definition | Instrument used | Technique followed |
|---|---|---|---|
| Ear length or Physiognomic Ear length (PEL) | Measured from the uppermost point of the pinna to the lowermost point of the lobule. (A1-A2) | Sliding Calliper | Verma et al (23) |
| Ear breadth or Physiognomic ear breadth (PEB) | Measured from the root of the ear to the maximum convexity of the helix. (B1-B2) | Sliding Calliper | Verma et al (23) |
| Ear length above tragus | Measured as the uppermost point of the pinna to the tragion. (A1-A3) | Sliding Calliper | Verma et al (23) |
| Distance from tragus to helix | Measured from the highest point on the tragus to the point on the outer side of helical curvature. (C1-C3) | Sliding Calliper | Verma et al (23) |
| Distance from tragus to antihelix | Measured from the highest point on the tragus to the point on the antihelix curvature. (C1-C2) | Sliding Calliper | Verma et al (23) |
| Lobule height | Measured from the lowermost point of the attachment of the external ear to the head (otobasion inferior) is extending to the caudal extension of the earlobe free margin (subaurale). (A4-A2) | Sliding Calliper | Verma et al (23) |
| Lobule breadth | Measured from the most caudal attachment of the ear lobule to the head and the outermost maximum transverse width of the ear lobule. (D1-D2) | Sliding Calliper | Verma et al (23) |

Furthermore, by using these measurements, following indices were calculated following Ahmed and Omer (30):
-Auricular Index = Physiognomic ear breadth/Physiognomic ear length × 100.
-Lobular Index = Lobular width/Lobular length × 100
-Lobular ear Index = Lobular length/ Physiognomic ear length × 100

### Data analysis

The data was entered into MS-Excel computer program. The statistical analysis for computing descriptive statistics (such as mean, standard deviation) of various parameters/ measurements of the ear was calculated using IBM-SPSS Statistics (Statistical Product and Service Solution) software version 20.0. The data was first verified for normality using graphical and confirmatory tests. Both approaches confirm that only three variables were found to be normally distributed whereas the rest of the variables were non-normally distributed. Therefore, both the parametric and its non-parametric equivalent tests were applied on the present data. Further, an independent t-test and Mann Witney-U test were applied for the evaluation of the differences between the sexes, and paired sample t-test and Wilcoxon Signed rank test were applied to assess the bilateral differences, thereby, highlighting the variations of ear morphology in the population under study. Moreover, the Discriminant function analysis was conducted to predict group membership for sex differences. A p-value of less than 0.05 was considered as statistically significant.

The inter-observer and intra-observer error was calculated by randomly selecting 20% (N=28) of the sample from the studied population. The obtained data for intra-observer and inter-observer error was examined using Technical error of Measurement (TEM), relative Technical error of measurement (rTEM) and coefficient of Reliability (R).

### Results

The normality of the data is determined using descriptive statistics, and the confirmatory test is shown in Table 2. The mean, median and standard deviation (SD) of linear anthropometric measurements and indices of left and right ear for both the sexes along with the confirmatory tests were shown in Table 3, whereas the statistics pertaining to the bilateral differences (left-right) were shown in Table 4. Further, Table 5 signifies the canonical discriminant function and multivariate test (Wilks' Lambda) for discriminant function analysis. The inter- and intra- observer error for the anthropometric measurements was demonstrated in Table 6.

*Table 2. Test of normality by descriptive statistics and Shapiro-Wilk test.*

| Variables | Side | Minimum (in cms) | Maximum (in cms) | Mean (in cms) | Median (in cms) | Mode (in cms) | Standard Deviation (in cms) | Shapiro- Wilk test | p-value |
|---|---|---|---|---|---|---|---|---|---|
| PEL | Left | 5.20 | 7.20 | 5.90 | 5.90 | 6.00 | 0.35 | 0.974 | 0.010 |
| | Right | 5.30 | 7.20 | 5.96 | 5.95 | 5.50 | 0.37 | 0.969 | 0.003 |
| PEB | Left | 2.40 | 3.85 | 3.16 | 3.15 | 3.20 | 0.25 | 0.991 | 0.524 |
| | Right | 2.50 | 4.00 | 3.19 | 3.20 | 3.30 | 0.27 | 0.993 | 0.708 |
| ELAT | Left | 1.90 | 3.10 | 2.50 | 2.50 | 2.30 | 0.27 | 0.989 | 0.320 |
| | Right | 1.75 | 3.50 | 2.65 | 2.68 | 2.90 | 0.27 | 0.985 | 0.138 |
| DfTtA | Left | 0.40 | 2.80 | 1.48 | 1.50 | 1.50 | 0.30 | 0.884 | 0.000 |
| | Right | 0.35 | 3.00 | 1.44 | 1.40 | 1.50 | 0.33 | 0.863 | 0.000 |
| DfTtH | Left | 1.60 | 3.00 | 2.38 | 2.40 | 2.30 | 0.24 | 0.971 | 0.004 |
| | Right | 1.10 | 2.85 | 2.33 | 2.35 | 2.40 | 0.27 | 0.913 | 0.000 |
| LH | Left | 1.00 | 2.20 | 1.69 | 1.70 | 1.60 | 0.18 | 0.965 | 0.001 |
| | Right | 1.05 | 2.25 | 1.66 | 1.70 | 1.70 | 0.18 | 0.984 | 0.112 |
| LW | Left | 1.20 | 2.45 | 1.92 | 1.95 | 1.90 | 0.25 | 0.979 | 0.028 |
| | Right | 1.25 | 2.40 | 1.80 | 1.80 | 1.80 | 0.23 | 0.990 | 0.404 |
| AI | Left | 43.65 | 63.39 | 53.51 | 53.13 | 50.00 | 3.99 | 0.988 | 0.292 |
| | Right | 44.09 | 64.29 | 53.57 | 53.48 | 50.00 | 4.12 | 0.987 | 0.193 |
| LI | Left | 65.79 | 156.77 | 114.54 | 113.55 | 100.00 | 16.77 | 0.990 | 0.455 |
| | Right | 67.57 | 171.43 | 109.26 | 106.56 | 100.00 | 17.25 | 0.979 | 0.027 |
| LEI | Left | 22.13 | 37.61 | 28.63 | 28.39 | 26.67 | 2.75 | 0.984 | 0.099 |
| | Right | 19.27 | 35.43 | 27.96 | 27.73 | 30.70 | 2.79 | 0.992 | 0.576 |

Where, PEL= Physiognomic ear length, PEB= Physiognomic ear breadth, ELAT= Ear length above Tragus, DfTtA= Distance from Tragus to Antihelix, DfTtH= Distance from Tragus to Helix, LH= Lobule Height, LW= Lobule Width, AI= Auricular Index, LI= Lobular Index, LEI= Lobular Ear Index

Based on the comparison rule of similarity, the present results were evaluated in a similar fashion as the left ear of a male was compared with the left ear of a female and vice versa while assessing the sex differences. Males showed higher values for all the ear measurements than their female counterparts. In the evaluation of sex differences, the mean values showed significant ($p<0.01$) results except in distance from tragus to anti-helix of right ear, lobule width of right ear, and lobule height of both the ears (Table 3). For the ear indices, significant male-female differences were observed for lobular ear index. Auricular index showed statistically significant sex differences only on the right side and lobular index showed it in case of only left ear (Table 3).

*Table 3. Anthropometric measurements (cm) and indices of right and left ear in males (N=71) and females (N=69)*

| Variables | Side | Males (N= 71) | | | Females (N= 69) | | | t- value/ Mann-Witney U test | P value |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Median | Std. | Mean | Median | Std. | | |
| Parametric Variables | | | | | | | | | |
| PEL | Left | 6.04 | 6.00 | 0.34 | 5.76 | 5.70 | 0.30 | 5.046 | 0.000 |
| | Right | 6.12 | 6.10 | 0.36 | 5.79 | 5.75 | 0.28 | 6.077 | 0.000 |
| DfTtA | Left | 1.54 | 1.50 | 0.23 | 1.43 | 1.40 | 0.35 | 2.263 | 0.025 |
| | Right | 1.49 | 1.50 | 0.26 | 1.39 | 1.35 | 0.39 | 1.838 | 0.068 |
| DftTH | Left | 2.43 | 2.45 | 0.21 | 2.33 | 2.35 | 0.27 | 2.649 | 0.009 |
| | Right | 2.38 | 2.40 | 0.24 | 2.28 | 2.30 | 0.28 | 2.273 | 0.025 |
| Non-Parametric Variables | | | | | | | | | |
| PEB | Left | 3.26 | 3.2 | 0.22 | 3.05 | 3.05 | 0.24 | 1239.50 | 0.000 |
| | Right | 3.32 | 3.30 | 0.23 | 3.04 | 3.00 | 0.24 | 991.50 | 0.000 |
| ELAT | Left | 2.57 | 2.60 | 0.24 | 2.41 | 2.40 | 0.27 | 1626.00 | 0.001 |
| | Right | 2.72 | 2.75 | 0.24 | 2.59 | 2.55 | 0.29 | 1753.50 | 0.004 |
| LH | Left | 1.68 | 1.65 | 0.21 | 1.69 | 1.70 | 0.16 | 2378.00 | 0.764 |
| | Right | 1.65 | 1.65 | 0.19 | 1.67 | 1.70 | 0.18 | 2256.50 | 0.419 |
| LW | Left | 2.01 | 2.00 | 0.22 | 1.82 | 1.85 | 0.25 | 1407.50 | 0.000 |
| | Right | 1.83 | 1.85 | 0.22 | 1.77 | 1.80 | 0.23 | 2099.50 | 0.143 |
| AI | Left | 54.01 | 53.97 | 3.79 | 52.99 | 52.73 | 4.15 | 2065.00 | 0.109 |
| | Right | 54.45 | 54.33 | 3.80 | 52.66 | 52.59 | 4.26 | 1816.00 | 0.008 |
| LI | Left | 120.30 | 122.22 | 15.68 | 108.62 | 109.68 | 15.86 | 1428.50 | 0.000 |
| | Right | 111.84 | 108.33 | 17.25 | 106.61 | 106.06 | 16.96 | 2093.00 | 0.137 |
| LEI | Left | 27.97 | 27.50 | 2.85 | 29.30 | 29.51 | 2.48 | 1629.50 | 0.001 |
| | Right | 27.02 | 26.87 | 2.69 | 28.93 | 29.27 | 2.56 | 1438.50 | 0.000 |

Where, PEL= Physiognomic ear length, PEB= Physiognomic ear breadth, ELAT= Ear length above Tragus, DfTtA= Distance from Tragus to Antihelix, DfTtH= Distance from Tragus to Helix, LH= Lobule Height, LW= Lobule Width, AI= Auricular Index, LI= Lobular Index, LEI= Lobular Ear Index

When the mean values of the left and right ear (bilateral asymmetry) were compared it was observed that a few measurements were higher on the right and others on the left side among males and females (Table 4). The measurements which were found to be higher in the right side of the ear were physiognomic ear length, physiognomic ear breadth and ear length above tragus while the distance from tragus to the helix, distance from tragus to antihelix, lobule length and lobule width were higher on the left side. All the measurements taken on the ear showed statistically significant side differences in males except lobule height. Among females, statistically significant side differences were shown for the ear length above tragus, distance from tragus to helix and lobule width (Table 4).

*Table 4. Bilateral differences in left and right ear measurements (cm) and indices in males (N=71) and females (N=69)*

| Variables | Males (N= 71) | | Females (N= 69) | |
|---|---|---|---|---|
| | Paired sample-t-test/ Wilcoxon Signed Ranks test | P-value | Paired sample t-test/ Wilcoxon Signed Ranks test | P-value |
| Parametric variables | | | | |
| Physiognomic ear length | -4.410 | 0.000 | -1.050 | 0.297 |
| Distance from Tragus to Antihelix | 2.490 | 0.015 | 1.473 | 0.145 |
| Distance from Tragus to Helix | 2.973 | 0.004 | 2.316 | 0.024 |
| Non-Parametric Variables | | | | |
| Physiognomic ear breadth | -2.922 | 0.003 | -0.365 | 0.715 |
| Ear length above Tragus | -5.417 | 0.000 | -5.500 | 0.000 |
| Lobule Height | -1.890 | 0.059 | -0.712 | 0.476 |
| Lobule Width | -5.855 | 0.000 | -2.527 | 0.012 |
| Auricular index | -1.181 | 0.238 | -0.801 | 0.423 |
| Lobular index | -4.121 | 0.000 | -1.454 | 0.146 |
| Lobular Ear Index | -3.220 | 0.001 | -1.209 | 0.227 |

The mean value of all the indices in the case of both males and females was higher in the left ear only except for the auricular index of males. Statistically significant sex differences were, however, recorded only for the lobular index and lobular ear index in the case of males only (Table 4).

Discriminant functional analysis was performed using the stepwise method with minimum partial F-value to enter was 3.84 and maximum partial F-value to remove was 2.7. Based on these parameters discriminant functional model was developed using the five best predictors i.e., right physiognomic ear length, right physiognomic ear breadth, right lobular height, left lobular width, and right lobular width. The discriminant function equation developed was written as follow:

P = - 16.131 + 1.965 x RPEL + 2.261 x RPEB – 2.652 x RLH + 2.666 x LLW - 1.933 x RLW

Where, P = Discriminant score, RPEL = Right physiognomic ear length, RPEB = Right physiognomic ear breadth, RLH = Right lobular height, LLW = Left lobular width, RLW = Right lobular width.

The group centroids were found to be 0.864 for males and -0.876 for females. So the cut score halfway between the two centroids was -0.0065. Therefore, if the individual's discriminant scores on the discriminant functional equation are above the cut score i.e. -0.0065, then the individual is probably male while it is female if the discriminant score is less than -0.0065.

The model was cross-validated using leave-one-out classification and showed 80.30% sensitivity and 82.60% specificity. Thus, there was high sensitivity and specificity of the population, in which the classification accuracy for predicting sexual dimorphism was 82.10%.

Table 5 signifies the canonical discriminant function and the multivariate analysis. The canonical correlation measures the extant of association between the discriminant scores and the set of variables that defines the group membership. The canonical correlation of the discriminant model in the study was found to be 0.659 which is moderately good.

*Table 5. Canonical Discriminant Function and Multivariate test (Wilks' Lambda)*

| Function | Eigenvalue | Canonical correlation | Wilks' Lambda | df | Sig. |
|---|---|---|---|---|---|
| 1 | 0.767 | 0.659 | 0.566 | 5 | 0.000 |

Whereas 0.767 eigen value was recorded for the discriminant model. The multivariate test is a goodness of fit statistics. The significance value for the multivariate test i.e., Wilks' Lambda was less than 0.01 which indicates that the model was a good fit for the data.

The inter- and intra-observer error was calculated for the present study. For this purpose, technical error of measurement (TEM), relative technical error of measurement (rTEM), and the coefficient of reliability (R) were considered and the corresponding values are presented in table 6. The reliability for the intra- observer error was found to be varied between 0.99 to 0.86 which are supposed to be in acceptable range according to Ulijaszek and Kerr (31). Similarly for the inter- observer error, the reliability varied between 0.97 to 0.85 except left and right distance form tragus to antihelix, right distance from tragus to helix and right lobular width.

## Discussion

An insight into the various structures on the face and characters is necessary for the reconstruction of the facial features in clinical research and forensic investigations. Ear morphology comprises features that fascinate the researchers for the establishment of the identity of the individual. According to the studies, indices and ear morphology serve as corroborative evidence and assist in the process of exclusion and inclusion in identification (26). Studies in the past have highlighted the bilateral and sex differences in the external ear

*Table 6. Inter- and Intra- observer error for anthropometric variables*

| Sr. No. | Measurement | Intra-observer error | | | Inter-observer error | | |
|---|---|---|---|---|---|---|---|
| | | TEM | rTEM | R | TEM | rTEM | R |
| 1. | Left Physiognomic ear Length | 0.008 | 0.133 | 0.992 | 0.039 | 0.616 | 0.956 |
| 2. | Right Physiognomic ear Length | 0.013 | 0.196 | 0.981 | 0.035 | 0.551 | 0.965 |
| 3. | Left Physiognomic ear Breadth | 0.011 | 0.323 | 0.949 | 0.019 | 0.544 | 0.867 |
| 4. | Right Physiognomic ear Breadth | 0.014 | 0.381 | 0.932 | 0.018 | 0.517 | 0.873 |
| 5. | Left ear length above tragus | 0.012 | 0.398 | 0.930 | 0.029 | 1.000 | 0.926 |
| 6. | Right ear length above tragus | 0.015 | 0.496 | 0.899 | 0.029 | 1.010 | 0.946 |
| 7. | Left distance from tragus to antihelix | 0.013 | 0.774 | 0.866 | 0.050 | 2.655 | 0.727 |
| 8. | Right distance from tragus to antihelix | 0.013 | 0.765 | 0.871 | 0.042 | 2.244 | 0.710 |
| 9. | Left distance from tragus to helix | 0.012 | 0.476 | 0.896 | 0.026 | 0.975 | 0.910 |
| 10. | Right distance from tragus to helix | 0.009 | 0.355 | 0.932 | 0.026 | 0.977 | 0.745 |
| 11. | Left Lobular height | 0.010 | 0.538 | 0.978 | 0.013 | 0.672 | 0.958 |
| 12. | Right Lobular height | 0.009 | 0.510 | 0.979 | 0.013 | 0.721 | 0.946 |
| 13. | Left Lobular width | 0.013 | 0.577 | 0.892 | 0.028 | 1.311 | 0.849 |
| 14. | Right Lobular width | 0.010 | 0.479 | 0.950 | 0.026 | 1.261 | 0.777 |

Note: TEM = Technical error of measurement, rTEM = relative technical error of measurement, R = coefficient of reliability.

(7,19-24). Ethnic differences have also been demonstrated by Alexander et al. (21) in the ear anthropometry. In the present study, the ear measurements was found to be statistically higher in males than females and the evaluation of bilateral differences showed significant differences for the various measurements of human ear. Observations of the present study were compared with the previously published studies for similar ages, and the differences amongst populations were shown (Figure 3, 4, 5, and 6). The ear measurements such as physiognomic ear length, physiognomic ear breadth, lobular height, and lobular width have been compared for the different populations studied previously.

Amongst all the populations studied, the present population was comparable with the Uttarakhand population (22) in the physiognomic ear length, while the physiognomic ear breadth was comparable between the present population and Turkish population (19) (Figure 3 and 4). Likewise, when lobular height and lobular width were compared, it was found that present population and the Uttarakhand population (22) reported comparable results in lobular height whereas, in lobular width, similar results were presented between the present population and Turkish population (19) (Figure 5 and 6).

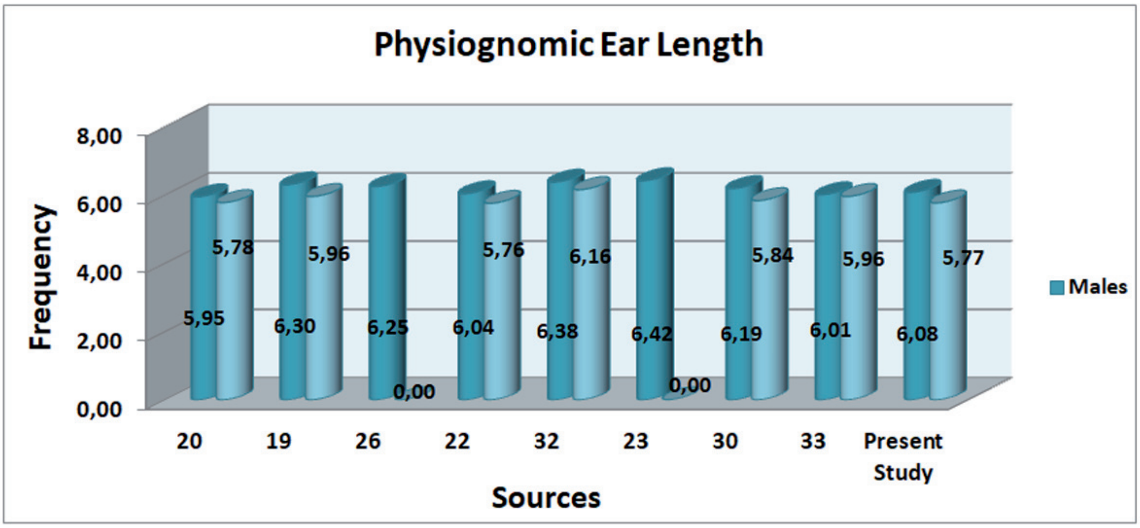


Fig. 3. Comparison of descriptive statistics of physiognomic ear length (cm) of the available studies with the present study. (Here 'sources' mean the available studies conducted by other authors)

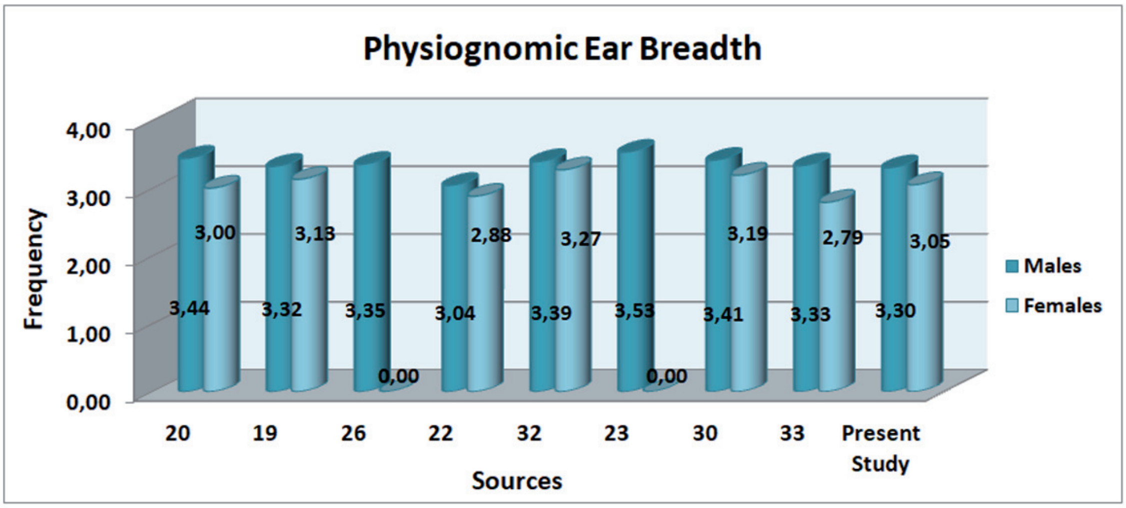


Fig. 4. Comparison of descriptive statistics of physiognomic ear breadth (cm) of the available studies with the present study. (Here 'sources' mean the available studies conducted by other authors)

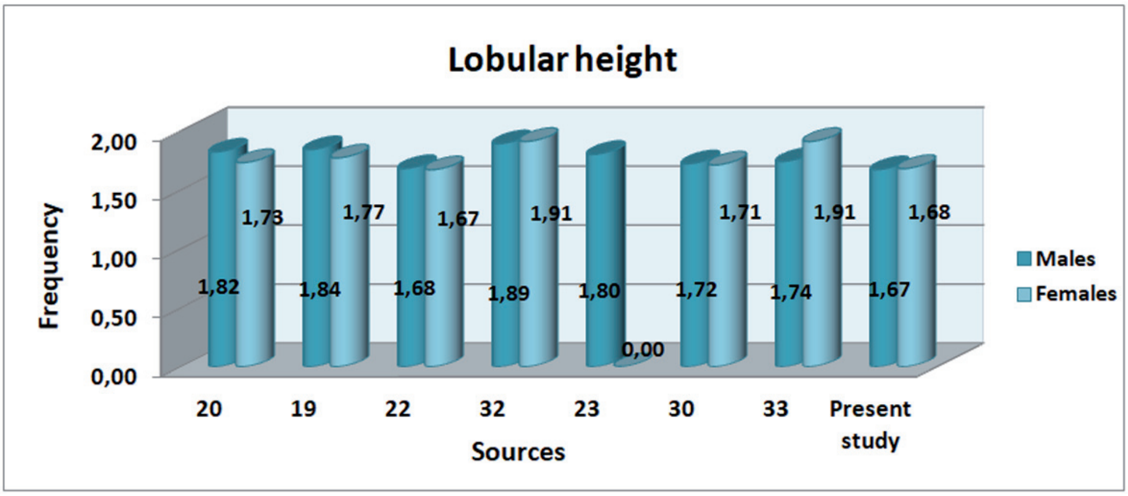


Fig. 5. Comparison of descriptive statistics of lobular height (cm) of the available studies with the present study. (Here 'sources' mean the available studies conducted by other authors).

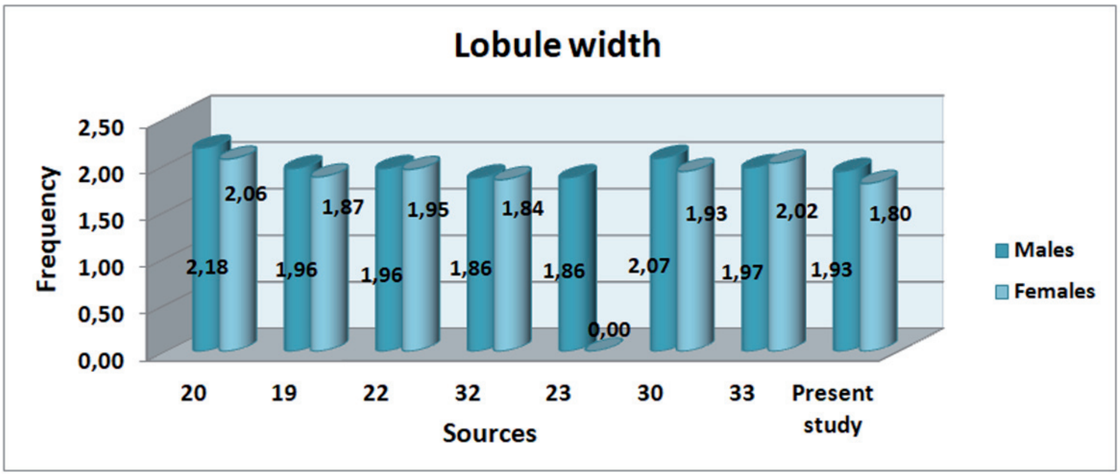


Fig. 6. Comparison of descriptive statistics of lobular width (cm) of the available studies with the present study. (Here 'sources' mean the available studies conducted by other authors)

There were a few studies that have been reported for ear length above tragus (20,23). It was observed that the value of ear length above tragus was the highest (3.15 cm) for males residing in Greater Noida, Uttar Pradesh (23). However, for the same linear measurement in the present population, the value reached 2.65 cm and 2.50 cm for males and females, respectively. Singh and Purkait (20) reported the ear length above tragus to be the lowest (2.03 cm in males and 1.85 cm in females).

It was noted that the value of the distance from tragus to antihelix in the study population was 1.50 cm and 1.40 cm in males and females, respectively. In contrast, the value of the same parameter reported in Turkish population was higher than the present population. Turkish population (33) has noted it to be 1.67 cm in males and 1.63 cm in females. However, another study on the Turkish population (19) documented almost parallel values i.e. 1.72 cm and 1.66 cm in males and females, respectively.

The present findings highlighted that the value of the distance from tragus to helix was the lowest with 2.43 cm in males and 2.34 cm in females in comparison to the Turkish population group. Turkish population (33) recently reported 2.64 cm in males and 2.60 cm in females, whereas the same population (19) documented 2.65 cm and 2.52 cm in males and females, respectively in an earlier research.

In comparison to the previously published research, it was found that the value of the physiognomic ear index in the Uttarakhand population (22) was 50.48 in males and 50.03 in females whereas in the present study, recorded it as 54.23 in males and 52.85 in females. In Sudanese Arabs (30), the values of this index was 55.06 in males and 54.67 in females while it was 54.00 in Kanyakubja male Brahmins of Lucknow in Uttar Pradesh State of North India (26). Therefore, based on the physiognomic ear index, one can deduce the shape of the ear, whether it is narrow, wide or long. It was assumed from the current research that if the value of physiognomic ear index is 50, then, the ear breadth is exactly half of the ear length which indicates that the individual has a proportional ear. Besides, if the value is greater than 50 then, the ear breadth is more than the half of the ear length which predicts that the individual has wider ears. In contrast, if the value of physiognomic ear index is less than 50, the breadth of the ear is less than the half of the ear length which further suggests that the individual has narrower and longer ears.

It has been observed that the value of the lobular index (177.18 in males and 147.25 in females) in the present population was much higher than the previously studied populations. However, the Uttrakhand population (22) reported it to be 118.20 and 117.68 in males and females, respectively. However, Ahmed and Omer (30) noted it to be 115.36 in males and 119.74 in females of Sudanese Arab. It can be figured out from the present research that the lobular index corresponding to 100, points out that both the lobular height and lobular width are equal. In addition, the value greater than 100 suggests lobular width is more than lobular height and thus, the lobule is wider and a value less than 100 indicates that lobular height is more than lobular width or the individual have longer lobule.

The lobular ear index evaluates the proportion of lobule in comparison to the ear length. The results of the lobular ear index for the present population observed no difference in the value of lobular ear index when compared with Sudanese Arabs (30). The present population reported it to be 27.50 and 29.13 in males and females, respectively, whereas the Sudanese Arabs reported it as 27.81 in males and 29.26 in females (30).

It can be concluded that these differences in ear measurements between different populations or different ethnic groups can predominantly be attributed to genetic factors, additionally to environmental and nutritional factors. To a greater extent, these differences further promote the development of population-specific standards. Sexual dimorphism exists in humans because of genetics and adaptation due to the division of labor. Many studies have corroborated the fact that the ear also exhibits these differences. The present study recorded significant sex differences ($p<0.01$) in physiognomic ear length and physiognomic ear breadth and the population of Uttarakhand (22) and Sudanese Arab (30) supports this findings; however, the Thakurs of Sagar district, M.P. (20) reported the significant results only on the right side for both the parameters. Murgod et al. (32) incorporated the subjects from almost all parts of India and observed the significant results except in left physiognomic ear breadth. Moreover, Acar et al. (33) studied the Turkish population and reported significant results only in physiognomic ear breadth. However, to the best of our knowledge, there is a paucity of research being conducted on ear length above tragus. The present research revealed significant sexual dimorphism for ear length above tragus, however the Thakurs of Sagar district; M.P. (20) evidenced significant sex differences for the right ear alone. Similarly, very few studies have reported the sexual dimorphism in distance from tragus to helix and distance from tragus to antihelix. The present study noted that there were significant sex differences for both parameters, and in addition, the study by Acar et al. (33) on the Turkish population showed opposing results.

The lobular height and lobular width were the most studied parameters of the ear as far as sex dimorphism is concerned. The study involving the Turkish population (33) showed significant results only in lobular height contrary to the Sudanese Arab (30) that reported the differing results. The present population showed significant sex differences only for left ear lobular width while the Thakurs of Sagar district, M.P. (20) evidenced significant results only for the right side of both the parameters. The present study has also incorporated the ear indices and an attempt is made to evaluate the sexual dimorphism in these indices. With the exception of the left auricular index, these indices also exhibit sex differences in the present sample whereas, the Sudanese Arab population noted insignificant results in the auricular index and significant results in the lobular index and lobular ear index. Conversely, a study conducted on Uttarakhand population (22) reported that the sex differences in auricular and lobular indices are statistically insignificant. These findings indicated that the ear measurements, as well as ear indices, were not only ethnic group-specific, but also population-specific. Therefore, there is a need to develop population-specific prediction equations for sex estimation, which can help the forensic and anthropological studies and casework.

Bilateral differences exist in almost all parts of the human body both anatomically as well as morphologically. Thus, an attempt was made to evaluate, whether the ear also exhibits these differences or not. Various studies documented bilateral differences in the ear dimensions (20,22,30,32,33). The present study found significant bilateral differences in physiognomic ear length, physiognomic ear breadth, lobular height, and lobular width in the males however, only lobular width showed significant differences in females. The Thakurs of Sagar district, M.P. (20) validated these results in case of males, but in the case of females, the Thakurs showed significant results in physiognomic ear breadth. The Uttarakhand population (22) showed insignificant bilateral asymmetry in almost all parameters in both males and females except lobular height in males. However, a study on Indian population by Murgod et al. (32) revealed insignificant bilateral asymmetry in physiognomic ear length in case of males and lobular height and lobular width in case of females. Turkish population (33) evidenced significant results only in physiognomic ear length in case of males and the remaining were insignificant in both males and females. In contrast, Sudanese Arabs (30) reported significant asymmetry in physiognomic ear length and lobular width in case of males, whereas there was significant asymmetry in physiognomic ear length, physiognomic ear breadth and lobular width in case of females.

Very few studies have documented the bilateral differences in ear length above tragus, distance from tragus to antihelix, and distance from tragus to helix. The present study revealed significant asymmetry in almost all these parameters in both the sexes except for distance from tragus to helix in females. Singh and Purkait (20) studied ear length above tragus and reported insignificant bilateral differences. On the other hand, Acar et al. (33) incorporated distance from tragus to helix and distance from tragus to antihelix for Turkish population. They reported insignificant results in the population except distance from tragus to helix in males in a Turkish population.

Bilateral differences in different ear indices were also not much studied in the literature. The current population recorded significant asymmetry only in the auricular index and lobular ear index in males. In contrast, the Uttrakhand population (22) reported insignificant asymmetry in these indices in both the sexes. Sudanese Arab (30) documented significant asymmetry in auricular and lobular index whereas insignificant asymmetry in lobular ear index in both the sexes. There were differences in the results pertaining to asymmetry in the indices in different populations, which further indicated that bilateral differences were also population- and ethnic group-specific.

## Conclusion

The present study provided a database of different ear parameters and also highlighted the sexual dimorphism and bilateral differences in ear morphometry among a population of Himachal Pradesh in North India. Physiognomic ear length, physiognomic ear breadth, ear length above tragus, distances from tragus to antihelix (left ear only), and tragus to helix exhibited significant ($p<0.05$) sex differences on both sides. Significant bilateral differences ($p<0.05$) were reported for all the measurements of the ear in males except for lobule height, whereas, significant side differences ($p<0.05$) were shown for ear length above tragus, distance from tragus to helix, and lobule width among females. The discriminant function model showed high sensitivity and specificity i.e., 80.30% and 82.60% respectively. Further, the model showed 82.10% accuracy for determining sexual dimorphism. Moreover, detailed studies on the human ear are required on larger population groups so that the database pertaining to its anthropological and forensic utility can be developed in different parts of India.

*Conflict of interest and Disclosure statement:*

The authors declare that there is no conflict of interest regarding this manuscript. The manuscript is in Compliance with Ethical Standards. This study is a part of Master's Degree dissertation submitted to the Department of Anthropology, Panjab University, Chandigarh, India**.** The nature of the research work was explained to the participants and written consent was obtained from each participant before initiating the study.

*Consent for publication*

All the authors have given their consent for publication of this article and approved the final version of the manuscript

*Availability of data and materials*

The study is a part of a Master's project and the raw data is available with one of the authors (DR) who has been nominated as a guarantor for the work. DR accepts full responsibility for the work and/or the conduct of the study, had access to the data, and controlled the decision to publish.

*Authors' contributions*

DR and KK conceived the idea of writing this paper. DR, KK, RS, NB, TK wrote the initial draft of the manuscript. DR collected the data and conducted analysis and compiled the results. DR, KK, RS, NB, and TK wrote and approved the final version of the manuscript.

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