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# Discriminant Function Analysis of Mastoid Measurements in Sex Determination

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**ABSTRACT** The purpose of this study was to develop a new standard for determination of sex of fragmentary human skeletal remains, using the mastoid process. It also attempts to assign rank to the commonly measured parameters of mastoid with regards to their sex discriminatory power. Logistic regression was also applied on mastoid variables to validate the results of discriminant functional analysis. The sample study (70 adult macerated skulls with known sex, 35 each male and female) was drawn from the Department of Anatomy and Forensic Medicine, Konaseema Institute of Medical sciences and Research Foundation, Amalapuram. Discriminant function analysis revealed that mastoid process correctly classified the sex in 90 percent of the subjects and mastoid length was found to be the best determinant for sex. A discriminant function equation specific for the present study skeletal population has also been derived from the variables.

## I. INTRODUCTION

The accuracy of sex classification with adult pelvis is greater than with adult skull (Phenice 1969); but pelvis is not always available for examination and diagnosis. Skull is probably the second best region of skeleton to discriminate sex (Bass 1971) and this was confirmed recently by Saini et al. in 2012. Moreover, in case of burning, petrous part of temporal bone is generally preserved because of its compact structure and protected position at the base of skull (Whall et al. 1980; Kalmey and Rathbun 1996). Mastoid region is one of the most dimorphic traits; in fact, direction of tip of mastoid process is sexually dimorphic: it tends to be vertical in male and pointed inward in females (De Moulin 1972; Suazo et al. 2008). The sexual dimorphism has been affirmed non- metrically by Hoshi (1962) and Laranach and McIntosh (1970). The osteometrics of mastoid process have been employed by Keen (1950) and later developed by Gilles and Elliot (1963), Vallois (1969), Demoulin (1972), Howells (1973), Nakahashi and Nagai (1986) and Nagaoka and Hirata (2005). Discriminant functional analysis provides sex-assessment criterion with regards to human skeletal remains; moreover it is objective and simple (Hsaio 1996). Its discriminatory effectiveness is more even with minimum number of traits. Careful determination of the metric parameters forms a cornerstone element of this type of analysis because of difficulty in intra-observer repeatability and intra-observer reproducibility (Nagaoka et al. 2008). Yet another problem is that efficacy of sex discrminant function is not sure in populations other than ones from which they have been derived. Keeping this fact in mind, Patnaik et al. (2010) have worked out a North Indian specific discriminant function equation for mastoid process of skull. Paiva and Segre (2003) introduced an easy technique for sex determination starting from the temporal bone, with a small observational error and with a high predictability degree. The technique is based on the triangular area calculation obtained between the points porion, mastoidale, and asterion, measured from xerographic copy of skulls. The presence of sexual dimorphism in the mastoid triangle has been recently questioned by Kemkes and Gobel (2006), on the basis of the studies of the asterion point localization, which position varies in the course of life (Day and Tschabitscher 1998).

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**Objectives**

The purpose of this study is to develop new standard for determination of sex of fragmentary human skeletal remains of South Indian origin, using the mastoid process. It is also tried to attempt to assign rank to the commonly measured parameters of mastoid with regards to their sex discriminatory power.

## II. METHODOLOGY

Seventy adult macerated human skulls (35 of either sex) of South Indian origin were studied to determine the accuracy of mastoid process in sex determination and ranking the variables with regards to their sex discriminatory power. The sample study was drawn from the Department of Anatomy and Forensic Medicine, Konaseema Institute of Medical Sciences and Research Foundation, Amalapuram. The skulls of known sex and already synostosed spheno occipital junction were included in the study. Only the skulls with no apparent deformity and intact mastoid process were included in this study. The mastoid measurements were taken on both sides by 2 observers. This was done in order to derive a more appropriate data. The average of two sides by both the observers was taken and measurement was noted. Likewise, 3 variables have been studied, namely mastoid length, mastoid medio lateral diameter and antero-posterior diameter of mastoid process. All the measurements were taken after taking proper training on biometric studies. With the skull lying on its right side and facing the observer, the fixed arm of the vernier calipers was kept tangent to the upper border of the auditory meatus (Frankfort plane) and mastoid length was measured from this line to the tip of the mastoid process. Medio-lateral diameter was measured as the distance measured between the highest surfaces of mastoid process within the digastric fossa to the most lateral point of the process on the same level. Antero-posterior diameter was measured as the distance between lowest point where tympanic plate abuts against anterior surface of mastoid process and the posterior border of the process on the same level. Size of mastoid process was obtained by multiplying the above said three variables and then dividing the product by 100. Univariate analysis was done for all the mastoid measurements by calculating mean and standard deviation and p value. Then students t test was used to distinguish between the male and female mean values for each variable. Then discriminant function analysis was performed by calculating Wilk's lambda, eigenvalue, canonical correlation and percentage of correct classification were quoted in assessing the relative validity of discriminant functions. Low values of Wilk's lambda, high values of eigenvalues, high value of canonical correlation and high value of percentage of correct classification are associated with excellent discriminant function. Discriminant functions were calculated with each single variable and also with all the variables combined together. The data obtained was tabulated and analysed using SPSS 14 software. Logistic regression was also applied on mastoid variables to validate the results of discriminant functional analysis.

## III. RESULTS

On the basis of univariate analysis, it was found that the Mastoid Measurements differ significantly among males and females at 5.0 percent level of significance (Table 1).

The discriminant functions calculated with each single variable are presented in Table 2. The best function in the present study is obtained by Mastoid Length which shows the lowest Wilk's lambda (0.46), the highest eigenvalue (1.18), the highest canonical correlation (0.74) and the highest percentage of correct classification (85.7%). The second best function is ob-

**Table 1: Group Statistics for mastoid measurements (N=70)**

| | *Male* | | *Female* | | *p-value* |
|---|---|---|---|---|---|
| | *Mean* | *S D* | *Mean* | *S D* | |
| Mastoid length | 29.233 | 2.4208 | 22.442 | 3.7715 | <0.001 |
| Medio lateral diameter | 11.248 | 2.0175 | 8.595 | 1.5218 | <0.001 |
| Antero posterior diameter | 16.553 | 3.8234 | 12.785 | 2.4757 | <0.001 |
| Size | 58.170 | 27.3638 | 26.880 | 13.8924 | <0.001 |

**Table 2: Variable wise calculation of discriminant functions**

| *Mastoid measurements* | *Wilk's lambda* | *Eigen value* | *Canonical correlation* | *t value* | *p-value* | *Correct classification M* | *F* | *Total* |
|---|---|---|---|---|---|---|---|---|
| All variables | 0.321 | 2.119 | 0.824 | - | <0.001 | 100.0% | 80.0% | 90.0% |
| Mastoid length | 0.458 | 1.182 | 0.736 | 8.965 | <0.001 | 91.4% | 80.0% | 85.7% |
| Medio lateral diameter | 0.638 | 0.567 | 0.602 | 6.211 | <0.001 | 80.0% | 82.9% | 81.4% |
| Antero posterior diameter | 0.739 | 0.352 | 0.510 | 4.895 | <0.001 | 71.4% | 85.7% | 78.6% |
| Size | 0.651 | 0.535 | 0.590 | 6.032 | <0.001 | 77.1% | 85.7% | 81.4% |

**Table 3: Discriminant function equation for determining sex**

| *Variable used* | *Discriminant equation* | *Cut off point* |
|---|---|---|
| Length | D= -8.153+0.316*ML | ½*(1.071 +(-1.071))=0 |
| Medio-lateal diameter | D= -5.552+0.560*MB | ½*(0. 742+(-0.742))=0 |
| Antero- posterior diameter | D= -4.554+0.310*AP | ½*(0.585 +(-0.585))=0 |
| Size | D= -1.960+0.046*SIZE | ½*(0.721 +(-0.721))=0 |
| All variables | D=-4.963+0.631*ML-0.565*MB-0.613*AP+0.076*Size | ½*{1.435+(-1.435)}=0 |

tained by medio-lateral diameter. On the other hand, the function produced by antero-posterior diameter shows far less discriminative capacity, as the function includes highest Wilk's lambda (0.74), the lowest eigenvalue (0.35), the lowest canonical correlation (0.51) and the lowest percentage of correct classification (78.6%).

The discriminant function equation for the determination of sex and their respective cut-off value has been given in Table 3. If the calculated discriminant score using the equation(s) is less than zero, the case is classified as "Female" and if the score is greater than or equal to zero, the case is classified as "Male".

A cross validation using leave-one-out method was employed to check how well the subjects are allocated to the groups.

Objective of discriminant analysis is to rank the variables according to their contribution for the separation of two groups.

Exploring the data with enter independence together method showed that:

(a) The mastoid length was the best predictor for sex determination among the four mastoid variables although the overall classification rate dropped from 90.0 percent to 85.7 percent.

(b) Mastoid breadth contributes less in sex determination.

Thus we may conclude that mastoid length is the 'best' discriminator and Antero-Posterior is the second best discriminator and size is the third best discriminator in the prediction of sex (Table 4). The external validity of the model was checked by Logistic regression which is robust against violation of normality and homoscedasticity.

**Table 4: Ranking of variables in determining the sex**

| *Variables* | *Function* |
|---|---|
| Mastoid length | 2.001 |
| Antero posterior diameter | 1.975 |
| Size | 1.658 |
| Medio lateral diameter | 1.010 |

## IV. DISCUSSION

The present study results stressed the usefulness of the mastoid region for sex determination. The accuracy of sex determination obtained by mastoid process measurements is similar or more accurate than some of the previous works like the studies conducted by Sumati and Patnaik in 2010 (76.7%), 77.0 percent by Stewart (1948), 80.0 percent by Kajanoja (1966), 85.0 percent by Keen (1950), 82.0-89.0 percent by Giles and Elliot (1963), 80-95 percent by Tanaka et al. (1979) and 90.0 percent by Hanihara (1959). The present study distinguishes itself from previous studies by focusing on sex determination using the mastoid processes which are often well preserved parts of fragmentary crania and also ranking the mastoid variables as per their discriminatory ability. Sumati and Patnaik (2010) has worked on mastoid process of North Indian skulls but no study has been carried out from South India and hence the present study was attempted. Moreover, separate discriminatory equation has been calculated based on each variable so that even by measuring one variable from a fragment of skull, the sex can be effectively determined.

Both metric and non- metric techniques have been used for studying sexual dimorphism of mastoid process; female skulls preserve infantile type of small mastoid process as observed by Klaatsch (1908). Hoshi (1962) classified mastoid process into three main types (male type, neutral type and female type) based on direction of mastoid process. Since this study is based on anthropometric techniques, it surpasses in importance the older study such as of Hoshi (1962). Moreover, by using more than one variable the present results have improved over the previous studies conducted by Schultz (1968), Helmuth (1968), Schaefer (1968) and Keen (1950). In the present study the mastoid process has been selected because it is recognized as being the most protected and resistant against damage and also due to its anatomical position at base of the skull. This has been demonstrated by Kloiber (1953), Wells (1960), Schaefer (1961), Gejval (1963) and Spence (1967). Patil and Mody (2005) selected 10 cephalometric variables to determine the sex, whereas Saavedra et al. (2003) used porion, mastoidale and asterion as the points to determine the sex of the skull via mastoid triangular area but was refuted by Kemkes and Gobel (2006) by stating that asterion location is population specific variable. Keen (1950), Giles and Elliot (1963) as well as Larnach et al. (1970) reported that females have smaller mastoid than males and similar results have been obtained by Sumati and Patnaik (2010) in North Indian Populations (Mean mastoid value for males is 60.18 and for females 30.99). Like the above the present study also revealed lesser mean mastoid values among females (26.88) than their male counterparts (58.17). Rogers et al. (2005) emphasized the value of Mastoid size as high quality trait in determining sex. Song et al. (1992) and Patil et al. (2005) also derived discriminant equation by using many cephalometric variables. Johnson et al. (1989) opined that the sex within each race is best described by a unique discriminant function.

In the present study, 70 adult human skulls were studied to know the accuracy of mastoid process in sex determination and to rank the variables according to their power of attribution to discriminate sex. Mean values of mastoid length, medio-lateral diameter, antero-posterior diameter and size of mastoid process were significantly more in males than in females. They were analyzed with highly objective discriminant function and it showed that the four variables, when put together, correctly determined the sex in 90 percent of the sample. Subsequent to stepwise discriminant function analysis, mastoid length was found to be the best sex determinant that, when used alone, correctly assessed the sex in 85.7 percent.

The discriminant function equation to determine the gender of skulls based on mastoid process has been computed by Sumati and Patnaik (2010) for North Indian population. The studies conducted in China by Song et al. (1992), Patil and Mody (2005) in Central India by Patil and Mody (2005) and among north Indian skulls by Sumati and Patnaik (2010) revealed that the sex within a given race can be best described by a unique discriminant equation. Thus, the discriminant function equation is unique to skulls of the present study population.

## V. CONCLUSION

The present study results revealed that the mastoid process can determine the sex in 90 percent cases. Amongst the sex discriminatory function of mastoid variables ranking stands as follows: mastoid length> mastoid antero posterior diameter> mastoid size > mastoid medio lateral diameter, when considered individually. This equation computed in the present study is specific for this area.

## VI. RECOMMENDATIONS

Similar work on other skeletal populations is needed to validate the discriminant function analysis to determine the sex at individual level. These studies will have more significance in forensic science and in other allied disciplines.

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