

# Identification of sex from humerus of skeletons using discriminant analysis: a study on contemporary Sri Lankan population

## Abstract

This pioneering study aims to identify significant differences in measurements between males and females and determine sex using the humerus, the long bone located between the shoulder and elbow joints, in the Sri Lankan population. We analyzed the maximum length, intercondylar breadth, vertical diameter, and transverse diameter of the left and right humeri, measured in millimetres (mm), from a sample of 86 humeri (46males and 40females) in Sri Lankan adults. To identify significant mean differences between male and female humeral dimensions, we employed paired sample t-tests and Wilcoxon signed-rank tests. Additionally, we explored linear and quadratic discriminant functions for each dimension and for combinations of dimensions to determine sex. It was found that all four humeral dimensions were significantly larger in males compared to females. The results indicate that the univariate quadratic linear discriminant function outperforms the linear discriminant function in estimating sex with higher accuracy. Both the left and right transverse diameters provide 99% accuracy in sex determination when using univariate quadratic discriminant functions, while the maximum length of the humerus showed the lowest accuracy. The multivariate discriminant process yielded lower accuracy compared to the univariate quadratic discriminant function. Based on these findings, we conclude that a univariate quadratic discriminant function utilizing either the left or right transverse diameter of the humerus is the most effective approach for predicting sex in the contemporary Sri Lankan population. This study is groundbreaking in providing insights into sex determination based on humeral measurements in the Sri Lankan population. The findings contribute to various fields such as forensic investigations, bio-archaeology, and medical research, where the accurate determination of sex is crucial.

**Keywords:** humerus, mean and variance difference, linear and quadratic discriminant function, sex estimation

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**Abbreviations:** ML, maximum length; VD, vertical diameter; TD, transverse diameter; IB, intercondylar breadth; SD, standard deviation; LTD, left transverse diameters; RTD, right transverse diameters

## Introduction

Skeletal remains are widely used in forensic anthropometry for criminal justice and to resolve body identification difficulties.<sup>1</sup> Also, unidentified human remains may create numerous problems at both legal and emotional levels for victims' families.<sup>2</sup> Moreover, one of the most important goals of forensic anthropology is to recognize the person by studying the skeletal remains and determine the gender, age, stature, body weight, body build, ancestry and socioeconomic status of the victim.<sup>3</sup> Further, an estimate of gender reduces parameters to be searched by approximately 50% when searching the reports of missing persons for an identification process.<sup>4</sup>

Therefore, sex estimation is the first essential step for the personal identification of the individual when a decomposed body is recovered.<sup>5,6</sup> Although various methods can apply to this process, such as DNA testing and fingerprint evaluation, in the case of severely damaged remains, especially mass disaster cases, fragmented remains, the above methods cannot be applied.<sup>7</sup> Thus, forensic anthropologists have an essential role in facilitating the identification of human remains by creating a biological profile through the analysis of age, sex, ancestry,

and stature.<sup>2,8,9</sup> The skull and some postcranial elements, such as the humerus, femur, and tibia, have been used for sex identification in forensic and archaeological cases.<sup>10,11</sup> Moreover, several studies have shown that sex estimation methods based on skeleton measurements are population-specific, and differences between the populations are demonstrated in some studies.<sup>12,13</sup>

Most skeleton elements have been subjected to discriminant function analysis for sex estimation, but little work has been done on the humerus.<sup>14</sup> Various parts of the skeleton, such as the scapula, femur, radius, and ulna, are used to estimate the sex of unknown human remains. The humerus is an effective bone for estimating sex because, even in a fragmentary state, it can give high classification accuracy.<sup>6</sup>

The maximum length (ML), vertical diameter (VD), transverse diameter (TD) and intercondylar breadth (IB) are the crucial dimensions of the humerus to estimate sex.<sup>15</sup> The present study is a pioneering study conducted in Sri Lanka to identify the sex using humerus and examine the differences in the dimensions between males and females. Sexual diagnosis of skeletons is of importance to physical and forensic anthropologists.<sup>13</sup> In medico-legal practice, statements on the probable sex of a decomposed body or part of a body are often expected even during an autopsy.<sup>16</sup> Further, identifying the sex with unknown remains of human skeletons is a crucial step for further investigation. Hence, this study will help to determine the sex of strange skeletons of humans in Sri Lanka.

## Materials and methods

A sample of 86 adults (46males and 40females) humeri were procured from the Department of Basic Sciences, Faculty of Dental Sciences, University of Peradeniya, Sri Lanka. Approval from the institutional ethical committee was obtained before the data acquisition of this study (ERC/FDS/UOP/1/2017/04). Moreover, all experiments were performed per the country's relevant guidelines and regulations. Four dimensions, maximum length (ML), vertical diameter (VD), transverse diameter (TD) and intercondylar breadth (IB) were taken into the study. Further, left and right-side measurements of the four dimensions were considered separately to determine the sex. Measurements were obtained using an osteometric board and a digital vernier calliper (Mitutoyo, Japan), and all these dimensions were measured in millimetres (mm). As this is the founding study conducted in Sri Lanka to identify sex using humerus, a limited dataset is available. Therefore, suitable statistical methods for small samples were used to ensure accurate results. Figure 1 shows an image of the humerus and the dimensions considered in this study, and Table 1 provides a detailed description of the data.



**Figure 1** Dimensions of Humerus, maximum length (ML), vertical diameter (VD), transverse diameter (TD) and intercondylar breadth (IB).

**Table 1** Description of dimensions and abbreviations used to denote the right and left measurements of the humerus<sup>8</sup>

Dimensions	Side		Details
	Right	Left	
Maximum Length (ML)	RML	LML	The distance between the most superior point on the head of the humerus and the most inferior point on the trochlea.
Vertical Diameter (VD)	RVD	LVD	Taken from the most inferior point on the edge of the articular surface of the bone across to the opposite side of the humerus.
Transverse Diameter (TD)	RTD	LTD	The diameter taken from the most inferior point on the edge of the articular surface across to the most posteriorly protruding point of the greater tubercle of the humerus.
Intercondylar Breadth (IB)	RIB	LIB	Distance of the most laterally protruding point on the lateral condyle from the corresponding projection of the medial epicondyle.

The Shapiro-Wilk test was used to verify univariate normality, while Mardia's test was applied to confirm the normality of multivariate variables. The null hypothesis of the Shapiro-Wilk test is that a single variable may follow a normal distribution. In Mardia's normality test, the presence of either skewness or kurtosis will lead to the rejection of multivariate normality. The null hypotheses of both normality tests are the same: there is no difference in the variances between the two independent groups. The Box-M test was applied to rectify the existence of equal variance of dimensions of humeri between males and females since it can be used for univariate and multivariate variables.

The paired sample t-test and Wilcoxon signed-rank test were chosen to identify the significant mean differences between the left and right-side dimensions of humeri. The paired sample t-test was applied with normally distributed sample data, while the Wilcoxon signed-rank test was used with non-normal sample data. The null hypothesis of both tests is that there is no difference in means between the data pairs. Moreover, the study applies the independent two-sample t-test, Welch two-sample test and Wilk-Lambda test for equal mean to confirm the unequal mean between males and females. It is recommended to use the independent two-sample t-test or Wilk-Lambda test if the sample variance is equal and Welch's two-sample t-test if the sample variance is unequal between two groups. Further, the Box-M test was chosen to explore the existence of equal variance between males and females.

To apply a Discriminant Function, the normality of variable and unequal group means are the pre-requisite conditions. The study considered both linear and quadratic discriminant functions for each univariate and multivariate variable. This leads to exploring the four combinations of the models; linear univariate, linear multivariate, quadratic univariate and quadratic multivariate discriminant functions.

A linear discriminant function is better for equal variances between independent groups, while the quadratic discriminant function is more reliable for unequal variances. However, this study applies a linear and quadratic function for all cases. Based on the level of accuracy of a model, the study decides the appropriate model to determine the sexual dimorphism of the contemporary Sri Lankan population. If the accuracy level of a model is very high, then the prediction would be more accurate for an unknown sample. The original and cross-validated data sets were used to find the level of accuracy of the discriminant models.

## Results

Table 2 shows the mean, median and standard deviation (SD) of the dimensions of the humerus for males and females. All median values were close to their mean values for all the cases. Moreover, the mean and median values of all dimensions are greater in males than in females. Further, the standard deviations for all dimensions except the left-sided maximum length and right-sided transverse diameter of the humerus were greater for males than females.

According to the results of the Shapiro-Wilk test for normality, all dimensions are distributed normally except for RIB and RTD (P-value<0.001). Table 3 demonstrates the results of Mardia's multivariate normality for four grouped dimensions of the humerus. The group with all left-sided measurements (LML, LIB, LVD and LTD) did not have multivariate normality due to the presence of skewness, while all other groups followed multivariate normality.

The Box-M test results for equality of measurement variance between males and females are given in Table 4. It concludes that the variance between males and females was equal for the measurement

of LML, LVD, RML, RVD and RTD and was not equal for LIB, LTD and RIB at a 5% significant level. Further, both grouped dimensions (groups with right and left) did not have statistically significant variance.

In order to check the mean differences among the pairs, the paired sample t-test was applied to normally distributed pairs of ML (RML-LML) and VD (RVD-LVD). In contrast, the non-parametric Wilcoxon signed-rank test was used for non-normally distributed pairs of IB (RIB-LIB) and TD (RTD-LTD). The results of both paired Sample t-test and the Wilcoxon Signed rank test are presented in Table 5. It concludes that the mean values of ML, IB and TD are significantly larger for the right side than the left, while the mean value of VD is significantly large for the left side than the right side at a 5% significant level.

Then the two-sample t-test was applied to equal variance dimensions of RML, LML, RVD, LVD and RTD, while Welch two-sample test was chosen to an unequal variance of RIB, LIB and LTD. P-values of the tests for all the variables (P-value<0.001) reveal that all left and right-side measurements are significantly larger for males than females at a 5% significant level.

Many studies<sup>5-9,17,18</sup> have used discriminant function analysis to determine sex. The left and right-side dimensions were considered separately for discriminant function analysis to classify sex since there is a significant difference between the left and right dimensions. For univariate cases, both linear and quadratic discriminant functions were chosen since there are equal and unequal variances in the dimensions among males and females. On the contrary, only the quadratic discriminant function was applied for multivariate cases due to unequal variances between males and females. Further, the stepwise deduction method was chosen to find all results of the discriminant function.

The results of all univariate linear discriminant analyses given in Table 6 show that raw coefficients on both left and right transverse diameters (RTD and LTD) of humerus had more significant impacts on predicting sex compared with other raw coefficients. Moreover, both the left and right vertical diameters of the humerus (RVD

and LVD) were good enough to predict sex. Additionally, all other univariate dimensions had less impact in predicting sex compared to the earlier four variables. The group centroids presented were greater than zero for males and less than zero for females, which explains that the mean value for a male is greater than a female. There were greater differences in the centroids between males and females for RTD and LTD, which means that it substantially contributes to determining sex.

The estimated accuracy of the linear discriminant function using original and 10-fold cross-validated data is presented in Table 7. Both right and left transverse and vertical diameters (RTD, LTD, RVD and LVD) provided a higher level of accuracy than other types of dimensions of the humerus. The univariate linear discriminant functions with RTD reported 99% accuracy for the original and cross-validated data set.

The accuracy levels of quadratic univariate discriminant functions using original and cross-validation data are presented in Table 8. Both left and right transverse diameter (LTD and RTD) provide 99% accuracy using univariate quadratic discriminant functions with cross-validated and original validation data sets. The RVD and LVD pairs show a higher accuracy level of 97% and 91%, respectively. In contrast, all other measurements revealed below 90% accuracy levels, where the maximum length of the humerus was the worst in predicting sex.

Table 9 displays the accuracy level for the multivariate quadratic linear discriminant function model using original and cross-validation data. It explored a 99% accuracy level for both sets of the multivariate case when the original data were used but slightly less when the cross-validated data set was used in the study.

Through the results of univariate linear and quadratic discriminant functions, the study concludes that either the right or left side of the transverse diameter of the humerus is perfect enough for sex identification while the dimension of maximum length of the humerus was the weakest to determine the sex. Further, it is demonstrated that the quadratic linear discriminant function is better than the linear model for the sex estimations since it provides more accuracy than the linear discriminant analysis.

**Table 2** Descriptive statistics of dimensions of humeri in males and females (in mm)

Dimensions	Male (N=46)			Female (N=40)		
	Mean	Median	SD	Mean	Median	SD
RML	321.09	325	15.39	289.8	291	13.61
LML	318.34	321	15	284.2	285	18.42
RIB	57.75	57.52	4.2	50.45	50.14	1.58
LIB	56.82	56.89	3.96	50.31	50.17	1.73
RVD	43.1	43.31	2.51	36.03	35.78	1.38
LVD	43.33	43.93	2.67	37.52	37.24	1.49
RTD	41.52	40.94	1.42	35.47	35.59	1.59
LTD	40.55	40.76	2.25	34.65	34.92	0.78

**Table 3** The results of Mardia's multivariate normality test

Dimension Groups	Test	Statistics	P-value	Decision	Multivariate normality
RML, RIB, RVD&RTD	Skewness	27.02	0.135	No skewness	Yes
	Kurtosis	0.95	0.342	No kurtosis	
RVD&RTD	Skewness	5.43	0.246	No skewness	Yes
	Kurtosis	0.04	0.965	No kurtosis	
LML, LIB, LVD&LTD	Skewness	33.26	0.032*	Skewness	No
	Kurtosis	0.5	0.616	No kurtosis	
LML, LVD &LTD	Skewness	15.67	0.109	No skewness	Yes
	Kurtosis	0.21	0.832	No kurtosis	

**Table 4** The results of box M test for equality of variance for males and females

Model	Box statistics	F-approximation	P-value
LML	0.568	0.545	0.461
LIB	6.604	6.361	0.012*
LVD	3.601	3.463	0.063
LTD	10.005	9.665	0.002*
RML	0.186	0.179	0.672
RVD	3.749	3.606	0.058
RIB	8.686	8.376	0.004*
RTD	0.171	0.165	0.685
(RML,RVD,RVD& RTD)	29.775	2.426	0.007
(LML,LIB,LVD& LTD)	16.579	2.383	0.027

**Table 5** Paired sample t-test and Wilcoxon signed-rank test for checking the mean differences

Pairs	Test used	Mean difference	P-value
RML-LML	Paired Sample t-test	3.606	0.0038
RVD-LVD	Paired Sample t-test	-0.613	0.0168
RIB-LIB	Wilcoxon Signed-Rank Test	0.5150*	0.0068
RTD-LTD	Wilcoxon Signed-Rank Test	0.8769*	0.0018

**Note:** \* Median difference was considered for the Wilcoxon signed-rank test

**Table 6** Results of univariate linear discriminant functions

Variable	Raw coefficient	Constant	Group centroids		Sectioning point	Mid-point
			Male	Female		
RML	0.067	-20.92	0.636	-1.46	-0.414	F < 305.44< M
RVD	0.446	-18.28	0.956	-2.2	-0.621	F < 39.57< M
LML	0.062	-19.16	0.644	-1.48	-0.419	F < 301.27< M
LVD	0.417	-17.35	0.735	-1.69	-0.478	F < 40.43< M
RTD	0.678	-26.91	1.242	-2.86	-0.809	F < 38.43< M
RIB	0.275	-15.27	0.609	-1.4	-0.396	F < 54.10< M
LIB	0.288	-15.82	0.569	-1.31	-0.371	F < 53.57< M
LTD	0.514	-19.91	0.918	-2.11	-0.596	F < 37.60< M

**Table 7** Model accuracy of univariate linear discriminant analysis for all the variables

Variables	Predicted accuracy(%) Original		Predicted accuracy (%) validated(CV)		Cross-average accuracy (%)	
	Male	Female	Male	Female	Original	CV
RML	91.3	80	82.6	60	87.9	81.8
RVD	91.3	99	91.3	99	93.9	93.9
LML	91.3	91	87.0	60	81.8	78.8
LVD	91.3	99	87.0	99	93.9	90.9
RTD	99	99	99	99	99	99
RIB	91.3	80	91.3	80	87.9	87.9
LIB	91.3	80	91.3	80	87.9	87.9
LTD	91.3	99	91.3	99	93.9	93.9

**Table 8** Model accuracy of quadratic discriminant function. predicted accuracy (%)

Variables	Predicted accuracy (%)		Cross-validated (CV)		Average accuracy (%)	
	Original		Cross-validated (CV)		Average accuracy (%)	
	Male	Female	Male	Female	Original	CV
LIB	91	80	87	80	88	85
LTD	99	99	99	99	99	99
RML	91	80	83	70	88	79
RVD	96	99	96	99	97	97
LML	87	70	87	60	82	79
LVD	91	90	91	90	91	91
RTD	99	99	99	99	99	99
RIB	99	99	91	80	99	88

**Table 9** Model accuracy

Variables	Predicted accuracy (%): original		Predicted accuracy (%) (CV)		Average accuracy (%)	
	Male	Female	Male	Female	Original	CV
RML,RIB, RVD&RTD	99	99	99	80	99	94
LML,LVD &LTD	99	99	96	99	99	97

## Discussion

Many studies conducted in different countries have considered the same four measurements; maximum length (ML), vertical diameter (VD), transverse diameter (TD) and intercondylar breadth (IB), that we considered in this study to determine the sex.<sup>5,6,13,16-19</sup> The maximum length of the humerus, intercondylar breadth and transverse diameter of the head were significantly greater on the right humeri. In contrast, only one dimension (vertical diameter of the humerus head) was significantly less for the left side of the humerus. Moreover, this study revealed that all four humeral dimensions were significantly larger for males compared to females. This is consistent with the findings of previous studies.<sup>6,8,17-21</sup> Many studies did not consider quadratic discriminant functions, and all the studies used linear discriminant functions to determine the sex.<sup>6,8,17,21</sup> The current study found that to predict sex, the quadratic discriminant function is better than a linear function for unknown Sri Lankans remaining. It might be the reason for quadratic that the present study involved less sample (N=86). In contrast, the sample size of all the previous study,<sup>8,17,21</sup> included in the literature survey varies from 64 to 387.

The present study found that only the transverse diameter of the humerus head determines the sex with 99% accuracy. Several studies<sup>8,17,19</sup> concluded that 2 to 3 dimensions of the humerus correctly predict the sex with more than 90% accuracy. However, some studies<sup>6,13,14</sup> demonstrated that sex could be predicted using one dimension of the humerus with more accuracy. Further, the same dimension was found to predict sex with more accuracy.<sup>6,13,14</sup>

Most of the studies<sup>6,8,14,17,19</sup> found that the vertical diameter of the humerus head had more accuracy varied from 82% to 96%. In some study,<sup>6</sup> it was provided with the most accuracy (95%) level to determine the sex. In the present study, only with this dimension sex can be estimated with a 91% to 97% accuracy level (by using the left (91%) and right (97%) side of the humerus vertical diameter of the head). Finally, the study found through stepwise deduction methods that univariate quadratic discriminant function with any sided transverse diameter of the humerus would best predict the sex of Sri Lankan population. The standards established in this study can be used to determine the sex of contemporary Sri Lankans in conjunction with other evidence available in profiling unidentified remains. A major limitation of this study was the smaller sample size.

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## Author contributions

This work was carried out in collaboration among all authors. Authors LSN and DN designed and supervised the study. Author TS managed the literature searches, performed the statistical analysis and wrote the first draft of the manuscript. Authors LSN and DN edited the manuscript. All authors read and approved the final manuscript.

## Conflicts of interest

The author declare that there is no conflicts of interest.

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