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Original article

Cross sectional, analytical study to derive the multivariate discriminant and stepwise discriminant analytical formula for sex determination from femoral variables from Maharashtra region in India.

Dr.Shital S Maske*, Dr. Prathamesh H Kamble**

*Assistant Professor, Dept of Anatomy, RCSM Government Medical college, Kolhapur,

**Assistant Professor, BJGMC, Pune.

Corresponding author: Dr.Shital S Maske

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Abstract

Introduction: The evolution is continuous process which also affects the structure of bones which is also influenced by environment, genetics, socio-cultural factors, diet. This leads us to think that it might be necessary to update the available present standards of skeletal identification. India is a vast country with a number of different populations but only a few studies pertaining to femur are available from this part of world and can not be applied to the other group. Moreover, most of the studies of sex determination have not used latest statistical techniques. Therefore, in the present study the femur was studied for setting the standards of sex determination in the population of Maharashtra, India using multivariate discriminant analysis and then stepwise discriminant analysis.

Material and method: 1068 adult human femora of known sex population available in bone banks of a various medical colleges in Maharashtra were studied for different 13 variables. Then student's t-test, multivariate discriminant analysis and stepwise discriminant analysis was applied to find out most accurate method and variables for sex discrimination.

Results: weight of femur had lowest Wilk' lambda and highest F-ratio and thus it was the best parameter among the others as a sex discriminator. Other parameters following the order are circumference of head, circumference of mid shaft, transverse diameter of head, physiological length, length of shaft, vertical diameter of head, transverse diameter of mid shaft, minimum AP thickness of neck, AP diameter of mid shaft, maximum length and the last two parameters in this order were angle of torsion and neck-shaft angle. Using this method of classification of femora86.07% male femora and 82.02% female femora were sexed accurately. Overall accuracy of classification was 84.08%. For Stepwise discriminant analysis weight, circumference of head and minimum AP thickness of neck were the best parameters and femora sexed accurately was 92.13% for females and 92.41% for male. The overall accuracy was 92.22%.

Conclusion: multivariate stepwise discriminant analysis improved the accuracy of classification of femora. The sectioning point (Z0) derived by the present study is a standard for the sexing the femora from Maharashtra region.

Keywords: Sex determination, Femur, Multivariate discriminant analysis, stepwise discriminant analysis.

Introduction

Violent crimes are on the rise worldwide and India is no exception. Several hundred unidentified remains are retrieved each year in a condition of advanced or complete decomposition (e.g. skeleton).In these situations, the expertise of Forensic anthropologists or Anatomists is often utilized to develop the identification profile like age, sex, ancestry and stature of deceased.Determination of sex from skeletal remains is generally the first step. In practicedetermining sex from human remains is in two ways: Morphological and Osteometric method. Morphological method results depends mainly on the experience and expertise and thus it involves subjective errors. So the osteometric analysisreduces intra observer errors.For the purpose of sex determination, the skull and pelvis are the highly reliable skeletal elements which can predict the sex accurately [1, 2, 3].But long bones have specially been used because of the ease of defining measurements, better preservation and so on.Among the long bones femur received special attention by researchers for the usage of femur in sex determination. The reason being, it is the most robust bone in human skeleton and therefore it is most likely to resist insult and decomposition.

In this regards, one must consider that the process of evolution which is continuously adapting and changing the structure of bones. It is also influenced by environment, genetics, socio-cultural factors, diet. This leads us to think that it might be necessary to update the available present data. Also there are plentiful evidences that standards of skeletal identification vary among different populations, even within a race group. The same standards cannot be used for another population.India is a vast country with a number of different populations but only a few studies pertaining to femur are available from this part of world. Moreover, most of the studies of sex determination have not used latest statistical techniques like multivariate discriminant analysis, stepwise discriminant analysis. Also there is no formula derived for ease of sex discrimination. Therefore, in the present study the femur was studied for setting the standards of sex determination in the population of Maharashtra, India using multivariate discriminant analysis and then stepwise discriminant analysis. Then to test which method is more accurate and to suggest the most accurate and best possible way for the sex discrimination of femoral remains.

Material and Method

The present study was conducted on 1068 adult human femora of known sex population available in bone banks of a various medical colleges in Maharashtra.Out of 1068 femora, 589 were male and 479 were female. All the femora were dry and only left sided. The reason for choosing the left side was based on reported observations that left lower limb is functionally dominant in majority of human being. [4]All the femora were free of damage or deformity and fully ossified indicating adult bones. Femora with pathological changes (i.e. cortical bone deterioration, extreme osteophytic activity, diffuse osteoarthritis and fracture etc) were excluded from the study. Age of the bone was above the age of epiphyseal fusion. Age contributes minimally to the sex discrimination function as suggested by Dibennardo and Taylor in 1979 [5]. Also this author opined that in the future studies age can be ignored.

Following measurements were taken for each femur:1. **Weight:** Weight of each dried femur was recorded with the help of scientific balance and Weights, in grams. [6] **2. Maximum length:** It was measured as the straight distance between the highest point of head and the deepest point on the medial condyle. Femur was placed with its dorsal side upwards on the osteometric board in such a manner that the medial condyle touches the short vertical wall, the movable cross piece touching the highest point of the head. Measurement was taken in millimeters.[6] **3.Physiological length:** Physiological length of femur was measured from the highest point on the head to the tangent to lower surface of the two condyles in anatomical position in millimeters with the help of Osteometric board. The two condyles were touching the short vertical wall of the Osteometric board. The movable cross piece was used to mark the head. Measurement was taken in millimeters.[6] **4. Length of shaft of femur:** Shaft length was measured in millimeters, from the lower margin of greater trochanter on the lateral side to the highest point of articular surface of the condyles on the anterior side, projected at right angle to the longitudinal axis. Measurement was taken with the help of first segment of Anthropometer, in millimeters.[6]**5.Vertical diameter of head:** Vertical diameter of head was measured as a distance between highest and deepest points of the head lying in the equatorial plane of the head, by holding the in such a manner that you can see the fovea centralis and avoiding the margins of articular surface of the head, calliper was rotated side to side until the maximum diameter was obtained. Measurement was taken with the help of sliding calliper, in millimeters.[6] **6. Transverse diameter of head:** Transverse diameter of head was measured as a distance between the most laterally projected points on equatorial plane taken at right angle to the vertical diameter of head and avoiding the margins of articular surface of the head, calliper was rotated side to side until the maximum diameter was obtained Measurement was taken with the help of sliding calliper, in millimeters.[6] **7.Circumference of head:** Circumference of head was measured at the same positions as the diameters along the four points marked by marker pen, with the help of flexible measuring steel tape, in millimeters.[6] **8.Minimum antero-posterior thickness of neck:** Minimum antero-posterior thickness of neck was measured in the narrowest part of the neck as a distance between anterior and posterior surfaces of the neck. Measurement was taken with the help of sliding calliper, in millimeters. [6] **9.Antero-posterior diameter of midshaft:** Antero-posterior diameter of midshaft was measured as a distance between anterior and posterior surfaces at the middle of the shaft. Middle of the shaft is the centre of length of shaft. Measurement was taken with the help of sliding calliper, in millimeters.[6] **10.Transverse diameter of midshaft:** Transverse diameter of midshaft was measured as a distance between lateral margins of the bone at the middle of the shaft; at right angle to the antero-posterior diameter of midshaft. Measurement was taken with the help of sliding calliper, in millimeters.[6] **11. Circumference of midshaft:** Circumference of midshaft was measured at the middle of the shaft where antero-posterior and transverse diameters were taken; with the help of flexible measuring steel tape, in millimeters.[6]**12. Neck- shaft angle**: Neck- shaft angle was measured on the anterior surface of the femur as the obtuse angle between the long axis of neck and the long axis of proximal part of femoral shaft. The neck axis is the midline between the proximal and distal borders of the neck, and the shaft axis is defined by the medio-lateral midpoints in the subtrochanteric and midshaft regions. Measurement was taken with the help of protractor; in degrees.[7] **13. Angle of torsion / anteversion**:The angle of torsion / anteversion was measured by Kingsley Olmsted method. The femur was placed on a smooth horizontal surface (a glass sheet on a table). The anteroposterior width of the neck was determined at the proximal and distal ends of the neck of femur by sliding calliper. The centre points of these two ends were then marked. A 1mm Kirschner wire was then placed along these two points using plasticine representing the central axis of the neck. This line was then continued to the surface supporting the bone. A devised protractor with a long metal arm was mounted at the same level on which the femur was placed. By manipulating this metal arm of protractor to the same level as the anteversion / torsion Kirschner wire under vision when both of these appeared overlapping the angle was read on the protractor to estimate the true angle of anteversion. [8]

Statistical Analysis

As the first part of study all the values were tabulated and analyzed statistically by routine statistical methods. The values of mean, standard deviation and range were obtained. Then the study results were analyzed using multivariate discriminant analysis function for which a standard computer programme, Statistical package for social sciences (SPSS 19.0) was used.The measured variables are taken as independent variables whereas sex is a dependant variable. This analysis calculated a discriminant function score and the canonical discriminant function coefficients, which included the raw coefficients, standard coefficients and sectioning points.A mean functional score for males (Zm) was obtained by subjecting mean values of all the variables of males to discriminant function. Similarly, mean functional score for female (Zf) was also obtained. The arithmetic mean of the mean values of males and females when put in place of variables in the formula gives the sectioning point (Z0). Any femora whose differential functional score falls on the male side of the sectioning point (Z0) will be categorized as male femur while that whose score falls on the female side of Z0 will be categorized as female femur. This enhances the accuracy of opinion.[9]

In the next part of study " Stepwise multivariate discriminant analysis" was used to see if there is improvement in accuracy of sexing by changing the set of variables and using only statistically significant variables. As discussed earlier the functional scores and sectioning points (i.e. Ym, Yf and Y0) were calculated for this analysis. [9]

Results

Table 1 depicts the mean and standard deviation of all the variables and the result of student's T-test. It shows that all the variables were significantly higher in male femora as compared to female femora except neck shaft angle which was higher in females but statistically non significant.

As a second part of study ' Multivariate discriminant analysis' was applied.The results are reported under the heading the Wilk's Lambda, equivalent F – ratio and calculated degree of freedom which are shown in Table 2. Wilk's lambda is a general test statistic used in multivariate tests of mean differences among more than two groups. This Wilk's lambda shows the percent contribution of each variable and determines the order of variable to enter in the function. Lambda ranges between 0 and 1. The value closer to zero indicates that the group means are different and the values close to 1 indicate that the group means are not different. Equivalents F-ratio provides strong statistical evidence of significant differences between mean of variables of male and female femora. More the value of F-ratio suggests that the variable is a better discriminator of sex.

Also this analysis calculates the canonical discriminant function coefficients, which included standard coefficients, structure coefficients and unstandardized / raw coefficients which are shown in Table 3.The standard coefficient indicates how much a given variable contributes to the overall classification.The structure coefficient measures the correlation between the variable and the function. It also indicates the contribution of each variable to a function.

The raw coefficients were used to calculate the discriminant functional score. The formula for discriminant functional score is -

Z = b0 + b1x1 + b2x2 + b3x3 + ----------------------------- + b13x13.

Where, b0 – constant raw coefficient, and b1,b2,b3,… - raw coefficient for each parameter, while x1, x2, x3,…… - means of the parameters. In the above formula mean value of respective male variables used then the score obtained is designated as Zm. The value of Zm obtained in our analysis isZm = 1.511304. Similarly, Zf is obtained by putting the mean value of female variables.Zf = - 1.16466. Z0 is the sectioning point which is obtained by putting the average values of mean of male and female variables in place of x.

$$Z_0 = b_0 + \frac{b_1 (x_{1m} + x_{2f})}{2} + \frac{b_2 (x_{2m} + x_{2f})}{2} + \ldots\ldots + \frac{b_{13} (x_{13m} + x_{13f})}{2}$$

The sectioning point obtained in present study isZ0 = 0.173321. Thus if the value of discriminant functional score of any unknown femur obtained is > 0.173321 then that femur is male and if it is < 0.173321the femur is female.Discriminant functional score was calculated for all the femora and each was then analyzed. It was observed that 506 out of 589 male femora score on male side of Z0 (86.07%) and 392 out of 479 female femora scored on the female side of Z0 (82.02%). Thus 898 of 1068 were accurately sexed (84.08%). These findings are shown in table 4 and histograph 1.

In an attempt to see if there is improvement in the accuracy by changing the set of variables and using only highly significant variables. We selected a 'stepwise discriminant analysis'. This statistical test is an attempt to find the best set of predictors for discrimination. In stepwise discriminant analysis, the most correlated variable is entered first by the stepwise programme then the second, until an additional variables adds no significant amount to the canonical R squared. The criteria used for adding or removing are typically the setting of a critical significance level for 'F'. [9]

Table no. 2 and 3 given the summary of multivariate discriminant analysis of the present study. The data reported under three headings: the Wilk's Lambda, equivalent F-ratio and calculated degree of freedom. Weight of femur had highest F-ratio (178.880) and least Wilk's Lambda (0.481) therefore this is the first variable out of 13 variables to enter in the stepwise discriminant analysis and this is the 1st step. Once the weight was analyzed, the remaining variables were reassessed and selected according to Wilk's Lambda level and F-ratio. The circumference of head having the least Lambda value and highest F-ratio was entered from the remaining variables as step 2. Next included in the analysis was the minimum antero-posterior thickness of neck of femur as step 3. The analysis was terminated after step 3, because of the extremely low value of F-ratio of the remaining variables, which was below the threshold of criteria for entrance.

Table no. 5 gives the summary of stepwise discriminant analysis of present study.After these steps of stepwise discriminant analysis the functions and their coefficients were obtained which is shown in table no 6. The raw coefficients were used to calculate the discriminant scores for the functions using the formula. Discriminant scores for the males (Ym), for females (Yf) and sectioning point (Y0) were calculated using the same formula as stated in the multivariate discriminant analysis.The discriminant score values obtained for stepwise discriminant analysis in the present study was as follows:Ym = 1.210847; Yf = - 1.37527 and Y0 = - 0.08221.

Thus if the value of stepwise discriminant functional score of any unknown femur is > 0.08221then that femur is a male femur and if the score is < 0.08221then that femur is a female femur.In the present study stepwise discriminant functional score was calculated for all the femora and each was then analyzed. It was observed that 544 out of 589 male femora and 441 out of 479 female femora were accurately classified. Thus overall 985 out of 1068 femora (92.22%) were accurately classified. These findings are depicted in Table 6 and histogram 2.

Table 1: showing mean and standard deviation of all the variables and result of t test

No	Variable	Male (Mean ± SD)	Female (mean ± SD)	P value (significance)
1	Weight of femur	300.65±45.4	203.88±48.02	<0.0001 (s)
2	Maximum length	443.67±22.6	398.63±26.6	<0.0001 (s)
3	Physiological length	440.28±21.10	396.44±26.60	<0.0001 (s)
4	Length of shaft of femur	356.75±17.47	320.49±21.81	<0.0001 (s)
5	Vertical diameter of head	139.90±5.71	123.18±10.04	<0.0001 (s)
6	Transverse diameter of head	84.15±4.61	74.74±4.95	<0.0001 (s)
7	Circumference of head	43.61±1.98	38.65±3.40	<0.0001 (s)
8	Minimum antero-posterior thickness of neck	43.48±2.10	38.34±3.19	<0.0001 (s)
9	Antero-posterior diameter of midshaft	24.18±2.35	21.13±2.03	<0.0001 (s)
10	Transverse diameter of midshaft	26.54±2.25	23.09±2.06	<0.0001 (s)
11	Circumference of midshaft	25.89±2.25	23.02±1.66	<0.0001 (s)
12	Neck- shaft angle	125.18±6.22	126.18±6.14	0.5547 (NS)
13	Angle of torsion / anteversion	13.92±2.69	12.08±2.77	<0.0001 (s)

(S: Significant difference, NS: non significant)

Table 2 : Multivariate analysis tests of equality of group means table showing Wilk's lambda, F-ratio and Degree of freedom.

	Variables	**Wilk's Lambda**	**F-ratio**	**Degree of freedom**
1	Weight	0.481	178.880	1
2	Maximum length	0.795	42.678	1
3	Physiological length	0.541	140.989	1
4	Length of shaft	0.544	139.037	1
5	Circumference of head	0.494	170.042	1
6	Circumference of midshaft	0.507	161.167	1
7	Vertical diameter of head	0.563	128.776	1
8	Transverse diameter of head	0.528	148.293	1
9	Minimum antero-posterior thickness of neck	0.672	80.999	1

10	Antero-posterior diameter of midshaft	0.762	51.907	1
11	Transverse diameter of midshaft	0.579	120.716	1
12	Neck shaft angle	1.000	0.35	1
13	Angle of torsion	0.897	19.049	1

Table 3:**Multivariate analysis tests Summary of the canonical discriminant function coefficients.**

	Variables	Standard coefficients	Structure coefficients	Raw coefficients
1	Weight	0.401	0.836	0.009
2	Maximum length	-0.118	0.815	-0.003
3	Physiological length	-0.337	0.794	-0.014
4	Length of shaft	0.316	0.761	0.016
5	Circumference of head	0.655	0.742	0.079
6	Circumference of midshaft	0.230	0.737	0.048
7	Vertical diameter of head	0.114	0.710	0.040
8	Transverse diameter of head	-0.398	0.687	-0.146
9	Minimum antero-posterior thickness of neck	0.185	0.563	0.085
10	Antero-posterior diameter of midshaft	0.047	0.450	0.017
11	Transverse diameter of midshaft	0.139	0.408	0.083
12	Neck shaft angle	0.125	0.273	0.012
13	Angle of torsion	0.049	0.012	0.018
14	Constant	-	-	-16.245

Table 4: Result of multivariate discriminant analysis showing percent of femora correctly identified.

	Male		Female		Average	
Total no	**No. correctly identified**	**%**	**No. correctly identified**	**%**	**No. correctly identified**	**%**
1068	506/589	86.07 %	392/497	82.02 %	898/1068	84.08 %

Histogram 1: Histogram showing the distribution of multivariate discriminant functional scores of male and female femora of present study.

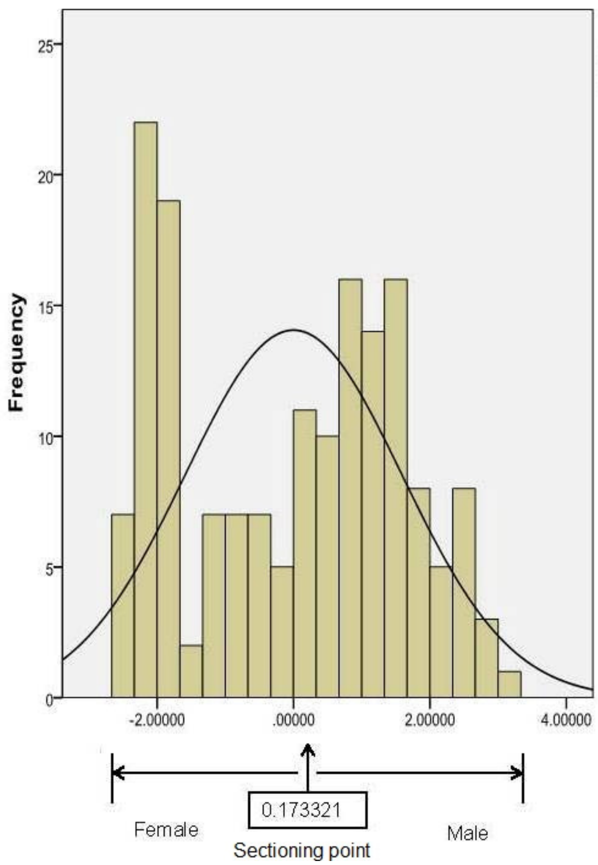

Table no 5:Summary of stepwise discriminant analysis.

Step	Entered variable	Wilk's Lambda	Equivalent F-ratio	Degree of freedom
1	Weight	0.481	178.880	1
2	Circumference of head	0.431	108.821	2
3	Minimum AP thickness of neck	0.418	76.201	3

Table no 6: Canonical discriminant function coefficient of stepwise analysis.

Step	Entered variable	Standard coefficient	Structure coefficient	Raw / unstandardized coefficient
1	Weight	0.534	0.879	0.111
2	Circumference of head	0.444	0.857	0.54
3	Minimum AP thickness of neck	0.252	0.592	0.115
4	Constant	-	-	-12.468

Table no 7: **Result of stepwisediscriminant analysis showing percent of femora correctly identified.**

	Male		Female		Average	
Total no	**No. correctly identified**	**%**	**No. correctly identified**	**%**	**No. correctly identified**	**%**
1068	544/589	92.41 %	441/497	92.13 %	985/1068	92.22 %

Histogram 2: Histogram showing the distribution of stepwise discriminant functional scores of male and female femora of present study.

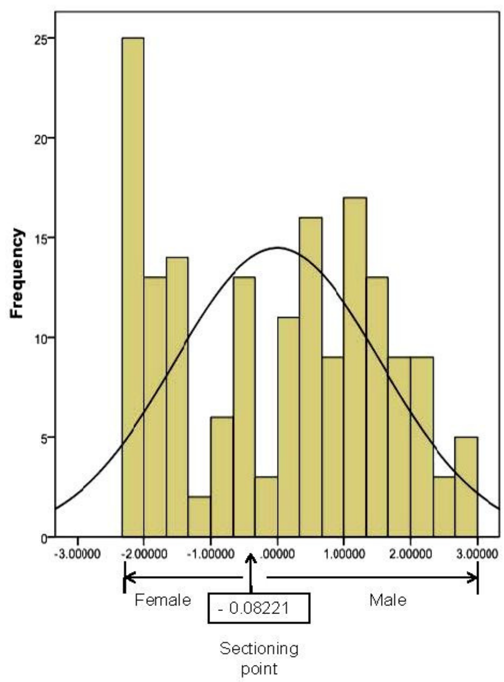

Table No. 8Comparision of discriminant analysis showing percentage accuracy in sex determination of femur from geographically diverse populations.

Study	Sample	Number & % of femora sexed correctly				Dimensions in function
		Male		Female		
		No.	%	No.	%	
Rumapurkait, 2002, Bhopal, India[14]	280	194/200	92.0	77/80	96.3	Maximum length + Maximum head diameter + Anteroposterior diameter + Epicondylar width
GargiSoni, 2010, Rohtak, India [4]	80	33/40	82.5	37/40	92.5	Maximum diameter of head + AP thickness of midshaft
Ismail Ozer, 2006, Japanese[15]	151	75/75	100	75/75	100	Maximum femur length + Trochanteric length + Transverse diameter of midshaft
Christopher King, 1998, Thai[16]	103	65/69	94.2	32/34	94.1	Maximum head diameter + Bicondylar breadth
Mario Slaus, 1997, Croatia [17]	160	75/80	93.75	75/80	93.75	Maximum length of femur + Maximum head diameter + Epicondylar breadth + Transverse midshaft diameter + Maximum femur head diameter + subtrochantericdiameter of femur + AP

						diameter of midshaft
Thomas Black, 1978, Missouri [18]	113	57/63	90.47	41/50	82	Midshaft circumference + Age in years
TomohitoNagaoka, 2009, Japan[19]	111	60 /68	88.23	52/62	83.87	Midshaft circumference
Robert DiBennardo, 1979, American Whites [20]	85	41/50	82	32/35	91.42	Age + midshaft circumference + AP diameter + Transverse diameter midshaft
M Steyn, 1997, S African whites[21]	105	48/56	85.7	45/49	88.6	Femoral head diameter + Femoral transverse breadth + Femoral distal breadth
Leelavathy N, 2000, Banglore, India[22]	160	68/70	97.14	59/31	93.44	Weight + Maximum length+ AP diameter of midshaft
Present study, 2011, Marathwada region	1068	544/589	92.41	441/479	92.13	Weight + Circumference of head + Minimum AP thickness of neck

Discussion

In the first part of study each parameter was analyzed to obtain mean, standard deviation and **Unpaired 't' test** was applied to examine the statistical difference between the means. The result showed all the variables were significantly higher in males as compared to females. The probable explanation for this is that, males are having more muscle mass and bulky body. To carry heavy body weight femur bone of males are heavier. This fact can be very well used for the purpose of sex determination. Also this sex difference can be the result of genetic factors, hormonal profile, environmental factors affecting growth and development (nutrition, physical activity) or the interaction of these factors. [10] Also due to reproductive function of the pelvis in the female, it is anatomically different from that of the male [1]. The muscular forces moving across the hip joint acting between the pelvis and the greater trochanter also has the impact on the femur head as suggested by Hirsch, Frankel 1960 [11] and France DL 1988. [12] They suggested that the articular surfaces of the bone receive a portion of the force being applied across them and extremities of the femur will react to such forces. Also the axial skeleton weight of the male is more than that of the female and this first brunt of this weight is borne by the head of femur which it dissipates. Thus effect of stress and strain will be reflected in its size and shape.

In the present study, mean neck shaft angle of male femurs was 125.18 ±6.22 degrees and for female femurs it was 126.18 ± 6.14 degrees. In females mean neck – shaft angle was greater but the statistical difference was found to be the non significant (P = 0.5547). According to Anderson JY and Trinkaus E 1998 [13] the neck shaft angle increases with more sedentary existences and with mechanizations. According to same authors the high neck shaft angle in female is because of lower physical activity levels relative to males.

Multivariate discriminant analysis results of the present study indicate that weight of femur had lowest Wilk' lambda and highest F-ratio and thus it was the best parameter among the others as a sex discriminator. Other parameters following the order are circumference of head, circumference of midshaft, transverse diameter of head, physiological length, length of shaft, vertical diameter of head, transverse diameter of midshaft, minimum AP thickness of neck, AP diameter of midshaft, maximum length and the last two parameters in this order were angle of torsion and neck-shaft angle.

Table no. 3 depicts the standard coefficients, structure coefficients and raw coefficients. The standard coefficient indicates how much a given variable contributes to the overall classification. And as could be expected from the above results, the circumference of head and weight of femur measurements added the most to classification. The structure coefficient measures the correlation between the variable and the function. It also indicates the contribution of each variable to a function. Once again the weight of femur and circumference of head had the highest correlation to sex discrimination function.

The raw coefficients were used to calculate the discriminant functional scores and the sectioning points. The sectioning point obtained for this function was 0.173321. Using this sectioning point the classification of femora shows that 86.07% male femora and 82.02% female femora were sexed accurately. Overall accuracy of classification was 84.08%.

While in the second part of multivariate analysis **Stepwise discriminant analysis** was applied. This test was applied to find out best set of predictors of discrimination and whether these set of variables improve the accuracy of classification. Table no. 5 and 6 gives the summary of stepwise discriminant analysis. The table shows that out of 13 variables 3 variables were selected for the analysis. These parameters were weight, circumference of head and minimum AP thickness of neck. The sectioning point obtained using these variables together was -0.08221. It was observed that using this sectioning point the femora sexed accurately was 92.13% for females and 92.41% for male. The overall accuracy was 92.22%. Thus the stepwise discriminant analysis improved the accuracy of classification.

Accuracy in % of Multivariate analysisVs Stepwise discriminant analysis			
	Male femora	Female femora	Overall
Multivariatediscriminant analysis	86.07 %	82.02 %	84.08 %
Stepwise discriminant analysis	92.41 %	92.13 %	92.22 %

Various studies including the present study have shown that combination of different variables give better accuracy for sex determination. In the present study best results were obtained with combination of weight, circumference of head and minimum AP thickness of neck (accuracy 92.26 %). The different combinations and their accuracies from geographically diverse populations are depicted in the table 8.

Conclusion

From the results of multivariate analysis we can conclude that even if only femora of the deceased are available, we can determine the sex of the deceased in 84% - 92 % accuracy.It is obvious that the multivariate discriminant analysis surpasses the statistical method in reliability as well as accuracy. The multivariate analysis and stepwise discriminant analysis is by far the best method for determination of sex of femora with available resources.

Findings of the present study may be useful in medico legal cases for estimation of sex from available femora. This study concludes that there exist sex specific and population specific differences in the osteometric measurements of femur. Present study has given the standards for the sex discrimination from femora which are specific to the Maharashtra region and in future these standards can be used as a reference for the sex discrimination from this region. In the present study, various measurements of the head like circumference of head, vertical diameter of head, and transverse diameter of head showed the differences in measurements of male and female femora. These measurements are important in surgical procedures like total hip replacement. Thus we strongly believe that such differences need to be considered when a total hip prosthesis is designed. There is a need for the sex-specific prosthesis design.

Future research needed

However, similar work needs to be done on all individual bones to enable anatomist to determine the sex of a deceased with maximum accuracy from any possible combination of skeletal remains.

Limitation of present study

A possible drawback to our method of study is the measurements were taken on dry bones and these dimensions may change during drying process. So the cadaveric studies with soft tissue in situ or intra-operative studies need to be done to delineate this issue.

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