Original Article

Reconstruction of Femur Length From Its Fragments in South Indian Females

Magendran Chandran,MD
Assistant Professor, Department of Forensic Medicine,Saveetha Medical College and Madras Medical College,Chennai, India.
E-mail: drmagi83@yahoo.co.in

Abstract:

Stature reconstruction from skeletal remains forms part of the forensic anthropological analysis for the purpose of identification of an individual. It is well documented from the previous studies that intact femur has the highest correlation with stature and as such widely used in deriving the regression equations. However, the femur is not always recovered intact in forensic cases. The aim of the present study was to estimate the length of femur from measurements of its fragments. This information is important in archaeological studies and forensic investigations, particularly when fragmented material is examined.

Sixty femora of adults' female individuals were selected for analysis. Maximum length and measures of seven fragments of the femur were obtained by means an osteometrical board and a digital caliper. Simples and multiple linear regressions were made to correlate each fragment with total length of the femur. Regressions formulae were obtained to define these estimates. The derived formulae are population specific and are designed for use in forensic skeletal analyses of South Indian females.

Key Words: *Forensic Anthropology Population Data, South Indian Females, Fragmentary Femur, Morphometry, Regression equation.*

Introduction:

Forensic anthropology is a field of forensic assessment of human skeletonised remains and their environment[1]. It is a sub-field of physical anthropology that has profound medico-legal implications. The question of identification arises in everyday medico legal practice in civil and criminal cases. Examination of skeletal remains recovered from a scene of crime, has often been used by the forensic anthropologists to extract relevant information about the victim. In a typical forensic anthropological analysis, this assessment includes the estimation of age, sex, race, stature, etc of an unknown individual.

Estimation of the stature is an important aspect in any medico-legal investigation. This is reiterated by the fact that stature estimation from various skeletal remains has been an area of vital interest to research workers for more than hundred years now[1].

Stature is usually estimated by the anatomical or mathematical method. The ‘‘anatomical’’ method of Fully for reconstructing stature, involving the addition of skeletal elements from the calcaneus to the skull[2]. In most of the cases, it is difficult to employ the anatomical method for stature reconstruction due to non-availability of the complete skeleton. The other method, i.e. the mathematical method is based on the relationship between lengths of long bones and stature. It involves the extrapolation of living stature from individual skeletal measurements by the utilization of ratios or regression analyses. Despite being a less precise method of stature reconstruction, the mathematical method, is workable even if a single long bone or bone fragment is available. This method employs bone length and stature tables, and regression formulae to estimate total skeletal height or living stature.

Different bones have been used in the estimation of stature. The conventionally used bones for stature estimation are the long bones (femur, tibia, fibula, humerus, ulna, radius), but the short bones of the hand and feet may also be used. Individually and collectively, the femur and the tibia are the most important components of stature. In humans, femur is the longest and largest bone[3, 4] which has the highest correlation with stature in intact state[1,5]. Therefore the best assessment of stature is obtained from the regression formula derived from femoral length.

However, in both archaeological and forensic practice, fragments of long bones (because of injury, mutilation, destruction, post-mortem gnawing by wild animals) are often presented as the only available source of identity. This renders the equations derived from the whole bone inappropriate for analysis. Stature thus estimated would be significantly inaccurate and the medico legal importance, significantly eroded. These medico legal situations emphasize the necessity to derive the regression equations from the fragments of femur. Thus the total length of the femur can be estimated from the fragments and later employ them in statural formulae to get reasonably accurate stature [6,7, 8].

Similar studies were done in different races viz., Steele and Mc Kern[9], Simmons et al in American population[6], Bidmos in South African population[7]. Many workers have reported significant differences in the proportions of the limb bone dimensions, due to the environmental and genetic differentiation [10-11]. India is characterized by wide variation in anthropometric dimensions among its population types. This necessitates the study in a more localized way to establish specific osteometric standards for different regions in India. Owing to this genetic and sex variations observed in different population groups, an attempt has been made in the present study to compute regression equations for the estimation of maximum femoral length from femoral fragments among south Indian females.

In the present study, the length of the femur was assessed anthropometrically in relation to the various fragments of femur. This study is an effort to derive regression equations for the reconstruction of the length of the femur from it fragmentary remains, based on its metric evaluation.

Materials & Methods:

Materials: From the unidentified, unclaimed female bodies coming for routine medico legal postmortem examination to the Institute of Forensic Medicine, Chennai, 60 adult femora for the study were collected during the period from 1st August 2008 to 31st July 2010.

Femora were removed by giving lateral skin incision in the thigh extending from hip joint to knee joint. The knee was flexed and the quadriceps tendon, the joint capsule and the cruciate ligaments were incised. The muscular attachments were dissected and by flexing and rotating the femur, the capsule of the hip joint and other ligaments were incised. The soft tissues were removed by treating the femur with antiformalin solution. By convention, the left side femora in each skeleton were measured, although the right side femora were substituted when the left was abnormal or missing. Any skeleton that showed features that would affect the measurements, such as pathology, surgical procedures, or any skeletal abnormality or deformity was not used in this study as this may influence the measurements.

Methods: The maximum length of femur was measured by osteometric board and the other following measurements were taken using Electronic digital vernier sliding caliper.

Definition of fragments:

FRAGMENT	DESCRIPTION
FML- maximum length of femur	linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle[12].
VHD- Vertical diameter of the femoral head	linear distance between the highest and lowest points of the head in the equatorial plane[12]
VHA- upper breadth of femur	linear measurement between the most superior point on the fovea capitis to the inferior aspect of the greater trochanter
VND- Vertical neck diameter	minimum diameter of femoral neck in a plane perpendicular to the head–neck midline[13]
FDL- Epicondylar Breadth	maximum distance between two most projecting points on lateral and medial epicondyles[12]
BCB- Bicondylar Breadth	most lateral and posterior projection of the lateral condyle, to the most medial and posterior projection of the medial condyle
MCL- Medial condyle length	linear distance between the most anterior and the most posterior points on the medial condyle.
LCL- Lateral condyle length	linear distance on the lateral condyle measured in an anteroposterior direction.

Descriptive statistics were produced on all data using the SPSS Statistical analysis software.

Then, correlation coefficients and standard error of estimate (SEE) were obtained. As a thumb rule, we shall consider correlation coefficient between 0.00 and 0.30 as weak, those between 0.300 and 0.700 as moderate and coefficients above +0.70 as considered high.

The correlation coefficients of the femoral fragmentary measurements to the maximum length of femur were studied both individually and in combination.

Regression equations were formulated from these coefficients. In the simple linear regression equations ($y = a + b x$) , y is the FML, a is the intercept, b is the slope, x is the measure of the predictor variable. Regression equation with the maximum length of femur as dependant variable and other measurements as the independent variables were obtained using the total sample (N=60).

FML was regressed on both individual measurements and combination of measurements.

Considering the possibility of any end of the femur (proximal or distal) being presented for forensic analysis, the regression equations were derived using the three measurements of the proximal end and four measurements of distal end independently.

Results

Descriptive statistics:

The maximum length of femur ranged from 36.4 cm to 42.6 cm, with mean of 39.5 cm amongst 60 female femora (table -1).

Simple linear regression:

All the measured variables showed significant positive correlation with FML. Generally, a low to moderate degree of correlation was observed. Medial condylar length displayed the highest correlation (0.627) with FML for an individual measurement (table -1).

Simple regression formulae:

Only the best regression equations with reasonable application are presented.

As MCL and VHA showed the highest correlation for an individual measurement, the regression equations were derived using the two variables. The equations showed moderate degree correlation (table -2).

Multiple linear regression:

The equations regressed from combination of different fragments displayed higher correlation coefficient (0.491 to 0.573.) and lower SEE (0.944 to1.013) (table -2).

When the three measurements of the proximal segment of the femur were combined, the regression equations exhibited moderate degree correlation (0.449- 0.415) (table -3). Similarly the equations derived

table-1

Measurements	N	Minimum	Maximum	Mean	Std. Deviation	correlaton with fml
FML	60	36.4	42.6	39.5	1.4	-
VHD	60	3.35	4.2	3.8	0.2	0.613(**)
VND	60	2.19	2.95	2.6	0.2	0.579(**)
VHA	60	7	8.76	7.9	0.5	0.618(**)
BCB	60	5.3	7.01	6.1	0.3	0.257(*)
FDL	60	5.91	7.14	6.6	0.3	0.414(**)
LCL	60	4.9	6.27	5.4	0.3	0.319(*)
MCL	60	4.67	5.77	5.2	0.3	0.627(**)

Descriptive Statistics of female femora & Correlations of Measurements of Fragments of Femur with Maximum Length of femur

NOTE: All the measurements are in cm.

*** Correlation is significant at the 0.01 level (2-tailed)*

*** Correlation is significant at the 0.05 level (2-tailed)*

Table- 2

Equations	Correlations	SEE
21.860+3.425(MCL)	0.393	1.087
25.774+1.731(VHA)	0.382	1.097
19.999+2.420(VND)+2.462(MCL)+0.57(VHA)	0.491	1.013
20.117+2.552(VND)+2.360(MCL)-0.142(VHA)+0.315(LCL)	0.496	1.017
23.443+1.859(VND)+0.607(VHA)-1.048(BCB)-1.118(LCL)+3.664(MCL)	0.573	0.944

BEST REGRESSION EQUATIONS FROM INDIVIDUAL AND COMBINATION OF FEMORAL FRAGMENTS TO DETERMINE FML

table -3

EQUATIONS	CORRELATIONS	SEE
23.656+1.784(VHD)+1.343(VND)+0.707(VHA)	0.449	1.054
25.479+1.819(VND)+1.173(VHA)	0.415	1.076

REGRESSION EQUATIONS FROM ONLY PROXIMAL FRAGMENTS MEASUREMENTS TO DETERMINE FML

from combining the measurements of the distal end of the femur showed moderate degree of correlation (0.452- 0.393) (table -4).

Discussion

During identification of skeletal remains, general demographic features like age, sex and race of the individual are determined first. To increase the identification further, estimation of stature of an individual is also vital for medico-legal investigations. For many years intact long bones have been used for stature estimation. But in many situations, the stature of the individual has to be calculated from the available material like incomplete skeleton, intact long bones or bone fragment.

Several researchers have used linear regressions to estimate maximum length of the long bones from measurements of their fragments and thereby stature. Simmons, Jantz and Bass (1990) analyzed Terry Collection skeletal remains and revised the maximum length of femur from its fragments[6]. Similar studies have also been conducted from fragments of the upper end of the radius & the lower end of the femur[14], ulna & tibia[8] and tibia alone[16].

As the factors like genetic diversity, isolation, differences in bio cultural history, hormonal, nutritional etc influence the skeletal development, regression formulae are population and sex specific. Regression formulae obtained in a specific population can underestimate or overestimate the stature, when employed in another population. Hence it was the aim of this study to derive regression equations from

TABLE-4

EQUATIONS	correlation	see
23.777-1.163(BCB)+0.861(FDL)-1.178(LCL)+4.559(MCL)	0.452	1.061
24.750-0.765(BCB)-0.989(LCL)+4.809(MCL)	0.437	1.065
22.994-0.968(LCL)+4.220(MCL)	0.416	1.075

REGRESSION EQUATIONS FROM ONLY DISTAL FRAGMENTS MEASUREMENTS TO DETERMINE FML

TABLE-5

Study	VHD	VND	VHA	BCB	FDL
Simmons White females present study females	0.596	0.409	0.632	0.445	0.537
black females	0.585	0.422	0.513	0.345	0.415
present study	0.613(**)	0.579(**)	0.618(**)	0.257(*)	0.414(**)

COMPARISIONS OF CORRELATION COEFFICIENTS

IN THE PRESENT STUDY AND THOSE OF SIMMONS ET AL.

TABLE-6

Study	VND	VHA	FDL	BCB	LCL	MCL
SAED FEMALES	0.544	0.623	0.781	0.722	0.753	0.724
IND SA FEMALES	0.681	0.799	0.720	0.746	0.696	0.619
present	0.579(**)	0.618(**)	0.414(**)	0.257(*)	0.319(*)	0.627(**)

COMPARISIONS OF CORRELATION COEFFICIENTS

IN THE PRESENT STUDY AND THOSE OF BIDMOS M A.

such fragments in South Indian Female Population. To estimate the maximum length of femur form fragmentary remains, it is important to identify accurately recognizable landmarks. In the study, we analyzed the fragments of the proximal and distal femur only, as the dimensions of the diaphysis are inappropriate because of difficulties on defining the precise landmarks. Three measurements

(VHD, VHA, VND) of the proximal end and four measurements (FDL, BCB, LCL, MCL) of the distal end were identified and selected in a sample of 60 adult female femora.

While considering the descriptive statistics, the mean values of most of the comparable measurements in Simmons study[6] and Bidmos study[7,16] are more than that of our study, people from Indian origin are shorter than the American and South African population sample considered by them. This result is also similar to the results reported in previous studies by Pearson & Bell (1917 – 1919). The mean values of bicondylar length (BCB) and vertical head diameter (VHD) are lower than the values as reported in previous studies by Pearson & Bell[1].

Correlation is a measure of association between two variables. In our case, it is the strength of association of the maximum femoral length with its fragments.

In our study, all the measured variables displayed positive correlation with the FML (table-1). The distal fragment medial condylar length (MCL) showed the best correlation with FML.

While comparing the correlations of comparable fragments of Simmons study, the fragments VHA and VHD showed better correlations than other fragments similar to the latter study (table-5). While comparing the correlations of comparable fragments of Bidmos study, medial condylar length (MCL) showed the best correlation with FML, in contrast to FDL, VHA of SAED FEMALES and IND SA FEMALES respectively (tabel-6). This difference in the relationship between femoral length and measures of its fragments among populations, infers the genetic variations in skeletal development among different races, which reiterates that the regression equations should be derived in a population specific samples.

Since all the measurements in our study had positive correlation with the FML, it is prudent to derive simple linear regression (y = a + b x) by univariate regression analysis against the individual measurements to calculate FML from anyone of these markers (table-1).

The measurements of the fragments' medial condylar length (MCL) and Upper breadth of femur (VHA) have the superior correlation with FML in comparison to other fragments. Thus when the fragments of both femoral ends are available for the medico legal investigation, the maximum length of femur can be best calculated from the metric evaluation of medial condylar length (MCL) and Upper breadth of femur (VHA) fragments (table 2).

In our study, proximal and distal segments were analyzed separately, because we considered the possibility that any one of the femoral epiphysis may be available for analysis (table-3, 4). Hence in medico legal situations where any of the proximal femoral fragments is recovered, regression formula using the Upper breadth of the femur (VHA) measurement will prove more useful, as the VHD and VND have poor correlation with the maximum femoral length individually. The reliability of the calculated FML from the proximal fragments VHA, VHD and VND, is in the descending order. Whereas the order of reliability from the distal fragments is from MCL, FDL, LCL and BCB successively.

The correlations of the FDL, LCL and BCB, on its own, are very poor and should only be used in cases where the other fragments are not available.

The correlations tend to be greater where combinations of different femoral fragments rather than a single fragmentary length were used, indicating that it is preferable to estimate maximum femoral length using more than one fragment wherever possible, for higher predictive accuracy (table-2).

The usefulness of regression equations is generally assessed on the basis of their standard error of estimate. The most accurate regression equation is indicated by the formula that contains the lowest standard error of estimate. The SEE in our study is from 0.944 to 1.097, in contrast to the SEE (1.33 to 1.40) of Bidmos study[16]. Thus, the regression equations derived in this study using the femoral fragments are more accurate than the equations derived from the latter.

The regression equations derived from combination of different fragments (whichever available) produce the lowest error of estimates and therefore should be used as the first preference to estimate FML.

The calculated maximum femoral length can be used to estimate the stature of the individual from the fragments by the regression equations, tables or the multiplication factors already established by the various studies.

The greatest accuracy in estimating living stature from long bones length will be obtained when sex and ethnic identity are available. Thus it is possible to estimate stature of female individuals from the femoral fragments with reasonable accuracy by these regression equations in South Indian population. Necessary correction for soft tissue can be made to obtain the living stature in practical cases of forensic interest in a population specific geographic area.

The results are reliable, but further works need to be designed to get more accurate estimates in a larger sample considering the age factor as well. It can be considered as a pilot study in obtaining the regression equation to estimate the maximum femoral length from femoral fragments in a sex and population specific sample.

One important shortcoming of the present series is that stature calculation by this approach was based on combining two separate formulae (calculating the femoral length by this formula and then estimating the stature by multiplying factor) thereby compounding the error. Yet, the functions obtained for the ends of the

femur are of much practical use in cases of fragmented femora, as commonly observed in forensic and archaeological contexts.

Conclusion

Regression equations were derived for estimation of maximum femoral length from measurements of fragments of the femur among South Indian Females. All the fragmentary measurements in our study showed positive correlations with the femoral length (FML). Therefore the maximum femoral length can be estimated from fragmentary remains of the femur. The maximum length of femur can be best calculated from the metric evaluation of medial condylar length (MCL) and Upper Breadth of femur (VHA) fragments. It is preferable to estimate maximum femoral length using more than one fragment wherever possible, for higher predictive accuracy. In the absence of intact long bones, equations presented in this study can offer a reasonable estimate of maximum femoral length from which the stature can be estimated in sex and population sample.

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ABBREVIATIONS

FML: MAXIMUMFEMORAL LENGTH
VHD: VERTICAL DIAMETER OF HEAD
VND: VERTICAL DIAMETER OF NECK
VHA: BREADTH OF FEMUR
FDL: EPICONDYLAR BREADTH
BCB: BICONDYLAR BREADTH
MCL: MEDIAL CONDYLAR LENGTH
LCL: LATERAL CONDYLAR LENGTH
ISA: INDIGENOUS SOUTHAFRICANS
SAED: SOUTHAFRICAN POPULATION OF EUROPEAN DESCENT