
**“ ESTIMATION OF STATURE BY USING PERCUTANEOUS
MEASUREMENTS OF LONG BONES OF LEG AND
FOREARM IN SOUTH INDIAN POPULATION
- A CROSS SECTIONAL STUDY”**

by

DR. VINAY RUDRAPPA HALLIKERI

REGISTRATION NUMBER-BF 0109002

Dissertation

Submitted to the

KLE UNIVERSITY, Belgaum, Karnataka

**In partial fulfillment
of the requirements for the degree of
M.D. (DOCTOR OF MEDICINE)
in
FORENSIC MEDICINE & TOXICOLOGY**

**Under the guidance of
Dr. Manjulabai K.H .MD**

**DEPARTMENT OF FORENSIC MEDICINE & TOXICOLOGY
JAWAHARLAL NEHRU MEDICAL COLLEGE
BELGAUM – 590010**

MAY – 2012

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KLE UNIVERSITY

BELGAUM

DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation entitled, “**ESTIMATION OF STATURE BY USING PERCUTANEOUS MEASUREMENTS OF LONG BONES OF LEG AND FOREARM IN SOUTH INDIAN POPULATION-A CROSS SECTIONAL STUDY**”

is a bonafide and genuine research work carried out by me under the guidance of

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**ENDORSEMENT BY THE HEAD OF DEPARTMENT &
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LIST OF ABBREVIATIONS USED

\bar{x} = Mean

SD= Standard deviation

SE= Standard Error

t= Student 't' test

DF= Degrees of freedom

p= Probability test

r= Correlation coefficient

SEE= Standard error of estimate

CI= Confidence interval

ABSTRACT

BACK GROUND AND OBJECTIVES:

“Identification is an individual’s birth right”. Stature is an important primary characteristic which defines an individual’s identity. Only method available for stature estimation in south Indians is by using multiplication factors derived for Mysoreans and literature regarding regression equations of South Indian population is lacking, hence the current study was conducted with the primary aim of deriving regression equations and multiplication factors that can be applied for estimation of stature of South Indian population.

MATERIALS AND METHODS:

Stature and percutaneous lengths of Tibia, Fibula, Radius and Ulna on both sides of 300 students (Males-150, Females-150) between 20-30 year age group was measured using standard anthropometric instruments and analysed for Karl Pearson correlation. Simple regression equations and multiplication factors were established and validated.

RESULTS :

There was no significant difference in the percutaneous length of right and left bones in both sexes ($p>0.05$). There is a positive correlation between percutaneous lengths of Tibia, Fibula, Radius and Ulna with stature on both sides amongst both the sexes. A set of 24 regression formulae and 24 multiplication factors were derived for both sexes for right and left sides from percutaneous length of long bones of leg and forearm. In both sexes stature estimated by regression formulae and multiplication

factors was similar to average measured stature with an error of less than 1cm which was statistically insignificant ($p > 0.05$).

INTERPRETATION AND CONCLUSION:

There is a positive correlation between the long bones of the forearm and leg with that of stature. We have come out with new set of regression equations and multiplication factors .The regression equations and multiplication factors of present study can be used upon the South Indian population with fair degree of accuracy.

KEY WORDS: Anthropology; Stature; Percutaneous length; Tibia; Fibula; Radius; Ulna; South Indians.

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“Identification is an individual’s birth right”.¹ Identification in the medico-legal sense refers to the determination of individuality of a person. It can be complete or partial. Complete identification is a proven fact by itself, wherein all the data of the individual is available. Partial identification is one, where in, the data available is in bits / pieces, from which the complete individuality of the person has to be framed. The various parameters of partial (incomplete) identification are age, sex, race, stature etc.² Stature provides one aspect of an individual’s physiognomy and one piece of information that may prove to be an important aid in individual’s partial identification. As per standard dictionary “Stature” is defined as the height of a person or sometimes an animal in a natural standing position. Estimation of stature of an individual by any means is a part of science called Anthropology. Anthropology is a Greek word where “anthropos” means human being and “logos” means knowledge. It is a field of science that deals with the study of humans from their earliest beginnings on earth up to the present time.³ Forensic anthropology is the application of this anthropological knowledge and techniques in a legal context. This involves detailed knowledge of osteology to aid in the identification, to establish cause of death and time since death etc from the skeletal remains.⁴

The estimation of height of an individual is of more compelling concern to forensic and anthropology experts. The orthodox method for stature estimation is correlation between living stature and lengths of long bones. Consequently, many sets of regression equations have been developed for this purpose. The better known are Karl-Pearson; Dupertius and Hadden; and Trotter and Glessner. However, these methods are limited to long bones and applicable only to the western populations.⁵ In India Siddiqui and Shah; Singh and Soha; and Mehta and Thomas; and other researchers have also developed regression equations for the same.⁶ Earlier, studies

have been done on stature estimation by using different body parts and their measurements such as estimation of stature using foot and shoe dimensions, dimensions of hands and feet, long bones of the forearm, long bones of the lower limb, percutaneous tibial length, skull, etc. Also there are some methods to calculate stature in case of fragmentary remains with identifiable bony landmarks.⁷

Stature estimation is done either by anatomical or mathematical methods. The anatomical method comprises the measurement of the cranial height, length of vertebral column and of lower extremities to which factors of correction of soft tissues are added. This method is applicable only to a complete skeleton. In the mathematical method, the stature (in living or dead) is estimated from the length of individual bones. In this method, primarily bones of upper and lower extremity are used for estimation of stature. This method is applied in forensic osteology for the estimation of stature from human skeletal remains.⁸

The forensic experts are well aware of the fact that the complete skeleton may not be available at the scene of crime. Hence they may not be able to use anatomical method of stature reconstruction. Thus, the expert may have no choice than to use mathematical method of stature reconstruction due to its obvious advantage that it is workable even if a single long bone or its fragment is available for examination.⁹ In most advanced countries documented skeletal remains are available to the forensic experts. In India documented skeletal remains are not available for establishing the norms of stature reconstruction. In the absence of documented skeletal material the researchers have focused their attention towards living population groups of India and have taken relevant bone lengths over the skin and correlated them with the stature to find out the degree of relationship between them and subsequently formulated multiplication factors and regression formulae for long bones and their fragments for

reconstruction of stature.¹⁰ Thus, the studies conducted by researchers^{9,10,11,12} in India pertains to use of percutaneous measurement of long bones and their fragments for reconstruction of stature. Some of the studies^{9,13,14} have reported a significant difference in the proportion of the limb bone dimensions due to environmental, hereditary and dietary factors of the population, and have influenced the stature of a person. In a vast country like India the climatic conditions and dietary habits of different regions vary considerably, in addition to the racial and ethnical variations. It is opined that, the study of residents of one state are not necessarily applicable to residents of another state.¹⁵ Due to improved socioeconomic conditions, population especially in India, is getting taller, and relationship between height and length of long bones is changed. Hence, fresh formulae are needed for each generation.^{16,17} Regression formula and multiplication formulae (M.F.) formulated on a population needs to be revised at least once in a decade to have greater accuracy in the prediction of stature among the living population.⁹ Limb bone length is known to be the best indicator of stature because, the long bones have got a greater definite correlation to the height of an individual.¹¹

There is no universally acceptable formula to express relationship between stature and length of long bones of an individual. Estimation of stature of an individual in India by using formulae given by western workers involves an error of 5-8%.¹⁸ Various factors like race, sex, side of body, climate, heredity and nutritional status are attributed to variations in the ratios of length of limb bones to that of stature.^{16,19} Literature regarding regression equations from this part of the world is scant. However, the only available method for stature estimation in south Indians is multiplication factors derived for Mysoreans.⁶ Thus, this study on subjects from south India (Karnataka, Andhra Pradesh, Kerala and Tamil Nadu) is undertaken. Our study

will be useful for identification of a person by estimating stature when only a part of dead body is available.

Objectives

A. To derive regression equations and multiplication factors that can be applied for estimation of stature of south Indian population.

B. To find out the differences between the males and females with regards to application of regression equations and multiplication factors so obtained.

HISTORICAL BACKGROUND

The importance of relation between different parts of the body and height of person was considered of great importance by Sushruta and Charak, the great Indian surgeon and physician respectively for diagnosing and treating certain diseases.²⁰ In 1888 Rollet measured the length of long bones in fresh state and 10 months later in dry state of 50 male and 50 female cadavers. He observed an overall decrease in length by 2 cm during 10 months span. He published a table for estimation of stature from length of long bones (Humerus, Radius, ulna, Femur, Tibia and Fibula).²¹ In 1892 Manouvrier reassessed Rollet's data and got results close to actual stature estimation. He modified Rollet (1888) stature table by introducing his own table to estimate the stature, for each sex, by using the length of long bones. He also indicated that 2cm should be subtracted from stature obtained by means of his table in living.²² In 1899 Pearson developed and introduced the 'REGRESSION FORMULA' through regression equation for right side.²³ In 1924 Pan introduced the method of reconstruction of stature by 'Multiplication factor' (Average stature divided by average length of bone gives multiplication factor and multiplication factor multiplied by length of bone gives stature of body).²⁴ Various authors^{13,25,26,27} (e.g. Muller in 1935; Steele and Mckern in 1969; and Steele in 1970) have worked on estimating the stature from fragmentary portion of bone. Simmons T, Jantz R.L and Bas W.N in 1990, Holland T.D in 1992, Introna F.J, Stasi A.M and Dragone M in 1993 also worked on the technique and methods to estimate the stature when only fragments of long bones are available.^{28,29,30}

ESTIMATION OF STATURE BY REGRESSION FORMULAE

‘Regression Formulae’ have been most commonly adopted for the estimation of stature when only bones or their fragments are available. Regression formula is statistical measure of average relationship between two variables – one independent [long bone length (x)] and other the dependent [height of individual (y)]. Regression equation is obtained, by various statistical analyses which require Mean, Standard deviation, Coefficient of variation and its correlation, Regression coefficient, Intercept, and standard error of mean. In 1899 Pearson first introduced regression equation. He used regression formula for calculation of stature from length of long bones of right side in French male cadavers. He published paper titled ‘Reconstruction of stature of prehistoric races’ and opined that stature is an important racial character.²³ In 1929 Stevenson P.H worked on 48 northern Chinese male cadavers. He derived stature regression formulae and compared them with Pearson’s original stature regression formulae. He suggested that better results from regression formulae will be obtained by applying a formula peculiar to race itself than by applying a formula from a second race.³¹ In 1932 Mendes Correa A.A carried out a study on Portuguese population. He found that stature of living person was 20 mm shorter than the cadaveric length.³² His findings were in close agreement with that of Manouvrier’s data studied in 1892.²²

In 1950 Telkka measured long bones of upper and lower extremity of Finnish cadaver. He tabulated regression equation and established the possibility of estimation of individual stature by means of single bone. He opined that if bones are measured ‘wet’ ‘fresh’ or ‘green’ 2cm must be deducted from length of each bone.^{33,23} In 1952 Trotter and Gleser measured stature during life and measured long bones of both extremities after death in American White and Negro’s of 18 years and above. They established regression equation for stature

calculation and concluded that the increase in stature after 18 years is insignificant though the mean value indicate that maximum stature is attained at age of 24 year but there is no statistically significant change after 18 years.¹⁶ In 1957 Glaister J found out that to get living stature of a person 12.5mm for male and 20mm for female should be deducted from cadaveric stature.³⁴ In 1958 Dupertuis C.Wesley and Hadden J.A calculated formulae for estimating living stature from dried long bones of American White and Negroes in Hamann-Todd collection. The American white stature was found to be 8.5 cm taller than Pearson's calculated stature and American Negro's stature was found to be 4-6cms taller than Pearson's calculated stature. Therefore they formulated new regression equations and concluded that stature can be more accurately predicted by using a formula which is derived from bone of comparable dimensions.³⁵ In 1958 Trotter and Gleser worked on 4 major races, White, Negroes, Mongolians and Mexicans. They established regression equations using long bones and concluded that each races needed different formulae for estimation of the stature of individuals belonging of each of these races.³⁶

In 1996 Yayim yili derived mathematical formulae for stature estimation in the Turkish population. Stature from tibial length was measured in 31 females and 49 male individuals on whom medico-legal autopsy had been done. Here 2cm was deducted from stature of corpse. Age based correlation were carried out using Trotter and Gleser's formula in individual beyond 30 years. $(\text{Age} - 30) \times 0.06 \text{ cm}$ was added to ante mortem stature.

He gave correlation coefficient of 0.71 in males and 0.62 in females. He also observed that application of formulae derived for American, European, Asian and African population led to suboptimal values for Turkish population.³⁷ In 2001 Munoz J.L, Linares Iglesias M, Suarez Penaranda J M, Mayo M, Miguens X, Rodriguez Calvo M S measured stature of 104 healthy

adults from Spain. They used anteroposterior teleradiography of limb to measure length of Femur, Tibia, Humerus, Radius and Ulna. On application of Pearson's regression formula, they found male Femur to be most accurate predictor of stature ($R = 0.851$) where as in females best result were obtained with tibia ($R = 0.876$).³⁸ In 2003 Duyar Izzet, Pelin C estimated body height based on tibia length in 231 randomly selected Turkish male and established subgroups according to body height (short, Medium, tall). They used general formula and group specific regression formula to estimate height in each subgroup. They found that group specific formula gives more accurate height estimates for individual in extreme height categories and are more reliable.³⁹ In 2002 Radoinova D studied 416 autopsy cases (286 male and 130 female adult Bulgarians) and found that Stature regression analysis provide better and more reliable results of stature estimation for the Bulgarian population than any other formulae.⁴⁰ In 2005 Celbis O in his study on 80 males and 47 females found that a positive correlation exists between stature and the length of long bones(Radius and Ulna) when the regression analysis was used.⁴¹ In another study in 2006 by Sarajlić N on 50 male cadavers, of individuals between the ages of 23 to 54 years, the cadaver length was measured and the length of the long bones was obtained from X-ray photographs. This study established that using Trotter and Gleser's formulae underestimate stature of tall people in the population of Bosnia and Herzegovina and they also suggested that there is no statistically significant difference between the length of the bones from the left and right sides of the body and recommended formulae developed from the average length of bone pairs for use.⁴²

In 2008 Blessing C Didia, E. Nduka, O. Adele worked on Nigerians. They used Tibial length, height of subjects and regression models to establish formulae specific to Nigerians. They measured height and tibial length of 200 adult Nigerians (96 male and 104 female).

They obtained general formulae for males and females which are reliable for the Nigerian population compare.⁴³ In a similar study done by Petrovecki V in 2007, the stature of 19 female and 21 male adult cadavers was measured within 24 hours after death. The antero-posterior radiographs of all limbs were taken, and the maximum length of the six long bones was measured from radiographs. There was a significant difference in the stature and maximum length of long bones between female and male cadavers ($p < 0.001$ for all). Regression equations specific to the Croatian population were computed separately for each long bone in males and females and proven to be reliable in predicting the living stature of the individual.⁴⁴ In 2007, Zhou XR A conducted a study on 365 healthy adults, the statures and digital radiographs of their right upper extremity long bones were measured. It was concluded that Digital radiograph measurement of the length of the upper extremity long bones seems to be a simple and practical method to estimate human stature in forensic practice.⁴⁵ Another similar study by Fan T. in 2008, The length of tibias and fibulas were measured in radiography, on 422 subjects (207 men and 215 women). The body height of each subject was also recorded Thirty five regression equations which were statistical significant were obtained and it was concluded that the lengths of tibias and fibulas on the x-ray films could be helpful to estimate stature. These equations could be used to estimate the body height of the Han population in North China.⁴⁶

In 1961 Bhargava Indra and Kher G.A derived regression equations by long bones of upper and lower extremity in 100 adult Bhils males and 100 adult Barela males of Madhya Pradesh. They reported that the equations for these two religions were different from each other.⁴⁷ In 1964 Patel M.P, Joshi N.B. and Dongre A.V estimated total height from

measurement of tibial length in 50 male medical students of Gujrat with age range of 18 to 22 years. They reported 2 things:-

1. The age factor is not important.
2. The regression equations so derived were valid for estimation of stature of male Gujarati's with fair degree of accuracy.⁴⁸

In 1965 Joshi N.B, Patel M.P, and Amin M.G. and Dongre A.U. opined that for finding out total height of an individual the knowledge of both Tibial and Ulnar lengths is of importance even though height can be predicted by regression equation of height on Tibial length or Ulnar length alone.⁴⁹ In 1976 Kate and Muzumdar obtained Regression formula for Indian bodies especially for Maharashtra and Punjab and found the different values for two sexes. They have observed that these regression equations differ significantly from Pearson's formulae derived from English bone.¹² In 1987 Nath S, Duggal N, Chandra S.N. estimated stature through percutaneous length of Ulna and Tibia among Lodhas of district Midnapur, West Bengal. They suggested that long bones particularly of lower long bones of lower provide excellent means of calculating a probable height.⁵⁰ In 1998 N.K Mohanty measured standing height and percutaneous tibial length of 1000 living adult individuals comprising of 500 Oriya males of age ranging between 20 – 77 years and 500 Oriya female of age 20 – 80 years. He found significant correlation between tibial length and height of an individual. Regression coefficient was found to be highly significant for both sexes. The estimated height was found in close approximation with that of observed height and was concluded that it is possible to estimate the height of a deceased person whose mutilated leg portion is only available for autopsy examination.¹¹ In 2004 Mukta Rani, Tyagi A.K, Verma S.K, Kohli A studied 300 (200 male and 100 female) students in age group 18 – 22 years. Total number of

cases(both male and female) were divided according to age(in years) in four groups 1)(18>19), 2) (19 > 20) , 3) (20>21), 4) (21>22) .The percutaneous length of both sides of Tibia were measured separately and regression equation were formulated for each groups and also for total population together to find out if single equation can be used for all age groups or an independent equation is required separately for an individual age group for estimation of stature. They concluded that there exists direct relationship between stature and length of leg bones. The difference in accuracy in estimation of stature using two types of equation was statistically insignificant. The height of person can be estimated by using the equations so derived.⁵¹

In 2009 Bhavana S. and Surinder Nath reconstructed stature among male and female Shia Muslims of Delhi using lower limb dimensions. They recorded stature, Femur length, Tibial length, Fibular length, Foot length and Foot breadth in 1011 Shia Muslims (503 male and 508 female) in age range of 20 – 40 years. Multiplication factor and linear regression equations for stature estimation were calculated. Analysis of data revealed that: Shia Muslim males are taller than Shia females and the sex difference was highly significant.

They concluded that Tibial length in males and Femur length in female provides best estimate of stature. Also dependability in predicted stature is better using linear regression equations for any of these body dimensions as compared to use of M.F (Multiplication factor).⁹ In 2009 A.K Agnihotri, S.Kachhwaha, V.Jowaheer, A.Pratap Singh estimated stature from length of tibia and ulna in Indo Mauritian population. They measured percutaneous Tibial and Ulnar length of 180 students comprising 90 male and 90 female in age of 18 – 28 years. They observed that there were no significant difference in length of right and left Tibia in both male and female. They observed that relationship between tibial length and stature is linear in Indo

-Mauritian population and same pattern exists between ulnar length and stature. They concluded that percutaneous length of Tibia and Ulna can be effectively used for estimation of stature using linear regression equation derived from the study.⁵² In 2009 Chavan S. K., Chavan K.D, Mumbre.S., Makhani C.S, estimated height from percutaneous Tibial length of 200 Maharashtrians comprising 100 adult male and 100 female in age group of 20-60 years. They observed that relationship between tibial length and stature is linear. They concluded that percutaneous length of tibia can be fairly used for estimation of stature using linear regression equation derived from study.⁵³

ESTIMATION OF STATURE BY MULTIPLICATION FACTOR (M.F.)

The Multiplication Factor is found to be second most commonly used method for estimating stature. Multiplication Factor is expressed as length of each bone relative to body height. In 1924, Pan in India introduced multiplication factor by measuring length of various bones and thereby established multiplication factor and calculated stature of the body.

$$\text{M.F} = \frac{\text{Average stature}}{\text{Average length of bone}}$$

Body stature = M.F. x Length of bone

He carried out study separately in male and female and also both together.²⁴

In 1927, Mehta and Thomas established multiplication factors for the long bones of upper as well the lower extremities on Mysoreans (Karnataka). These multiplication factors are in use for estimating the stature not only amongst Mysoreans but also have been extended to the south Indian population, till date.⁶ In 1931 Nat B.S. calculated multiplication factor for all the long bones and stated that 'the length of given bones is to be multiplied by its multiplication factor to estimate the stature'.¹⁴ In 1944, Siddiqui and Shah measured length of long bones -110 of upper and 110 of lower extremities of Punjabis to test accuracy of multiplication factor. They concluded that stature can be estimated with help of multiplication factor.¹⁵ In 1972 Lal C.S and Lala J.K estimated multiplication factors for Tibia and Ulna in 258 cases in both sexes in age group between 12 – 21 years in North Bihar population. The Multiplication Factors for Tibia and Ulna was calculated. They concluded that the difference between actual height and calculated height was very negligible. The multiplication factor remains constant in age group 18 – 21 year.¹⁷ In 2009 Bhavana and Surinder Nath in their study opined that multiplication factor for males varied from minimum of 3.16 to maximum

of 4.42. For females M.F. values varied from a minimum of 3.33 to maximum of 5.27 and were fairly accurate.⁹ In addition, for stature estimation, other researchers have used measurement of upper end of Radius and lower end of Femur- Mysorekar (1980)⁵⁴, and segmental Ulna and tibia – Mysorekar (1984)⁵⁵ and Tibia - Holland T.D (1992)³⁹, Dragone (1993)³⁰, Chibba and Bidmos (2007)⁵⁶. In 1931 Hrdlicka estimated stature from long bones in American white and Negroes. He calculated multiplication factor and percentage proportions. His findings were found to be similar to that of Pan (1924).^{24,57}

BILATERAL SYMMETRY

In 1937 Schultz studied American white skeleton and reported that there is Greater bilateral asymmetry in bones of upper extremity and Greater bilateral symmetry in bones of lower extremity.⁵⁸ In 1951 Dupertius Wesley and Hadden John. A stated that right side average value is more than left side except that of femur.³⁵ In 1952 Trotter and Gleser also reported that all bones on left side are longer.¹⁶ In 1957 Lowrance E.W and Latimer H.B studied the weight and linear measurements of 105 human skeletons from Asia. In their study they found that right sided bones of upper extremity were heavier and longer than left one. The lower extremity bones were more symmetrical with a tendency of the left side bone to be heavier and longer than right side. They also concluded that bones of lower extremity in general have fewer variables in weight and length than those of upper extremity, hence bones of lower extremity (Femur and Tibia) give better result in estimating the stature than those of upper extremity.⁵⁹ In 1965 Latimer H.B and Lowrance E.W found that left Femur is heavier and longer, the right tibia is heavier, while left Tibia and right Fibula are longer.⁶⁰ In 1978 Taylor and Halliday studied limb asymmetry in children- both normal and scoliotic and found that 14% of normal children and 21% scoliotic children showed lower limb asymmetry (difference of 10mm or more) with right lower limb being more larger in both population.⁶¹

In 2004 Mukta Rani, Tyagi A.k, Verma S.K, Kohli A observed that in males in 12.5% cases right Tibia was slightly more in length in comparison to left Tibia, whereas in 21% cases lengths of Tibia on both sides were equal and in 66.5% of cases left Tibia was more in length when compared to right Tibia. In females, the right side Tibia was found to be more in length in 65% cases and in 14% cases right tibia was slightly more in length in comparison to left tibia, whereas in 21% cases both tibial length were equal. Thus the inter-correlation for

bones of the lower extremity tends to be somewhat higher than those of upper extremity.⁵¹ In 2010 Kewal krishan, Tanuj Kanchan, John.A.DiMaggio studied sample of 967 adult male Gujjars. They assessed bilateral asymmetry in 6 limb dimensions i.e total upper extremity length, forearm length, arm length, hand length, total lower extremity length, leg length. Their results indicated statistically significant bilateral asymmetry in all these dimensions. Their study concluded a higher possibility of obtaining erroneous result while estimating stature from those body dimensions which show statistically significant bilateral asymmetry when formula developed from one side is used on the other side. They recommended that the examiner must first identify the side to which the limb belongs to and then apply the appropriate formula derived for that particular side.⁶²

a) Source of data and materials: The South Indian student population of JN Medical College and VK Dental college, Belgaum with their chronological age between 20 to 30 years.

b) Study design: Cross-sectional study.

c) Sample size: For the Simple regression equations with a single independent variable(x), the regression equation is of type, $y= A+Bx$, the sample required for such a study is 10, as total number of independent variables in this study are 4, total sample size will be $10 \times 4 = 40$, however considering easy availability of samples, sample size will be 300(males-150, females-150) in the current study.

d) Methodology:

Inclusion criteria:

1. Students hailing from Karnataka, Andhra Pradesh, Tamil Nadu, and Kerala.
2. Chronological age group above 20 to 30 years.

Exclusion criteria:

1. Students unable to stand
2. Chronological age less than 20 and more than 30 years.
3. Any pathological condition of bones and limbs e.g., fractures, dislocations, poliomyelitis, osteoporosis, rickets, scoliosis and kypho-scoliosis etc.
4. Congenital anomalies.
5. Dwarfism and gigantism.
5. Steroidal therapy.

e) **Data collection:** The study was performed in adherence to the principles established with the declaration of Helsinki (2000) and written informed consent was obtained for every student and all female subjects were examined in the presence of another female.

Various socio-demographic factors and the following anthropometric data were collected in the pretested proforma as registered in the annexure-3.

1. Standing height (Stature): The subjects were made to stand bare foot on a base-board of a **Stadiometer** with both feet in close contact with each other, trunk braced along vertical board with head oriented in ear eye plane.

The following measurements are percutaneous and were taken by **Spreading callipers**.

2. Length of Tibia: Subjects were made to sit in a chair keeping the knee in semi-flexed position and the foot slightly inverted. The distance between most prominent palpable portion of medial condyle of Tibia to the tip of medial malleolus was taken as the length of Tibia.

3. Length of Fibula: Under the same manoeuvre, the distance between most palpable portion of head of Fibula (just underneath the tendon of biceps femoris) to the tip of lateral malleolus represented the length of Fibula.

4. Length of Ulna: Subjects were made to flex their elbow joints completely. The distance between tip of olecranon process (farthest point of elbow) to tip of styloid process of Ulna represented the Ulnar length.

5. Length of Radius: Subjects were made to extend their forearms; then pronate and supinate the forearm alternately, so head of Radius was located and marked. The

distance between head of Radius to tip of Radial styloid process represented the length of Radius.

The measurements were taken on both the sides were documented in pretested proforma and later on documented on master chart and analysed.

f) Analysis Plan: The data was analyzed using various subroutines of statistical package for the social sciences (SSPS) software. Regression formulae and multiplication factors were developed for various combinations to reach the best estimate possible.

The regression formula is of type, $Y=A+B(X)$, it is a simple regression equation since here x is the only independent variable.

Here,

Y = Height of individual to be estimated,

A = Regression constant,

B = Regression coefficient,

X = Percutaneous length of the long bone (tibia/fibula/radius/ulna).

Multiplication factor for the individual long bones were calculated for each person and mean of all was calculated. The following equation was used to get the multiplication factor: $K=H/L$

Where, H = Height, L = Length of long bone (tibia/fibula/radius /ulna), K = A constant multiplication factor which was specifically determined for individual long bone from the various data so obtained.

After taking the measurements, statistical analysis is done using statistical regression equations as given below:

$$1) \quad \sum Y = Na + b\sum X$$

Where \sum = Sum value

Y= Value of stature

N= Number of cases studied

X= Value of percutaneous bone length

a= Unit greater than x value by y value

b= Regression coefficient

From the above equations, regression formulae, standard errors and coefficient of correlations were developed to fulfil the aims and objectives of the study. The regression equations and the multiplication factors so obtained were tested on a fresh sample (100) of south Indian population in order to validate the outcomes.

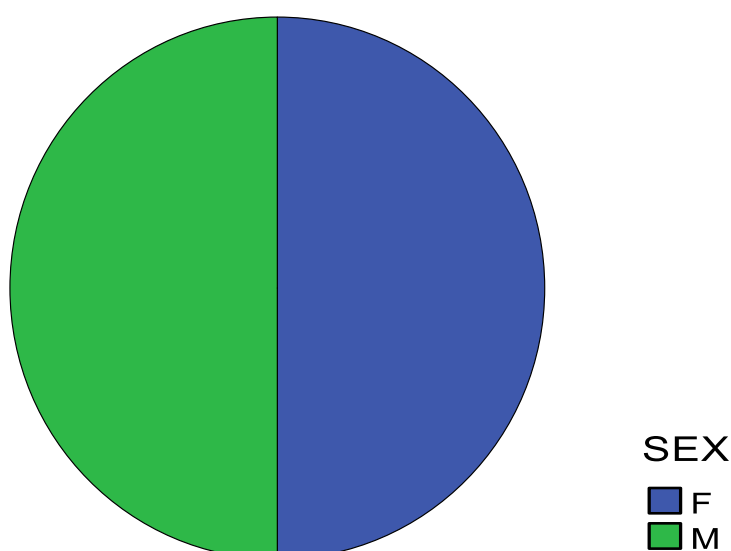
We have estimated stature amongst the south Indian students of JN medical College, Belgaum between the age groups of 20 to 30 years total number $n=300$, i.e. Males=150, Females=150.(Table No.1 and Graph No.1). The students were admixture of population from south India i.e. Karnataka=101, Andhra Pradesh=152, Kerala=17 and Tamil Nadu=28 (Graph No. 2). The average age was 24.5 years in males and 22.9 years in females. For both the sexes the average age was 23.2 years (Table no.1).

Table 1. Distribution of age.

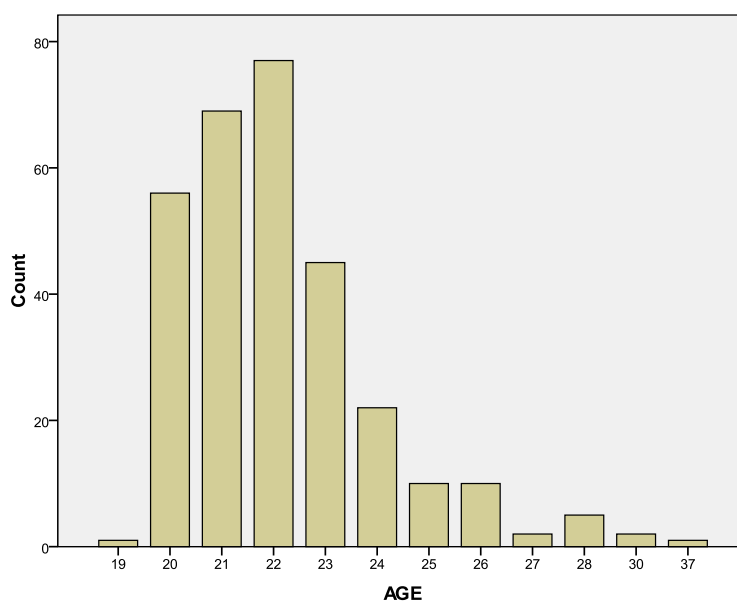
Sex	Sample size	Age(in years)	Minimum	Maximum
Male	150	24.5 ± 3.58 [SE = 0.29]	20	30
Female	150	22.9 ± 1.68 [SE=0.14]	20	28
Total	300	23.2 ± 2.10 [SE= 0.18]	20	30
Comparison of mean age of male and female.				
$t = 8.316$		$DF = 298$	$p = 0.000$	

t = Student t test, DF = Degrees of freedom, p= Probability test.

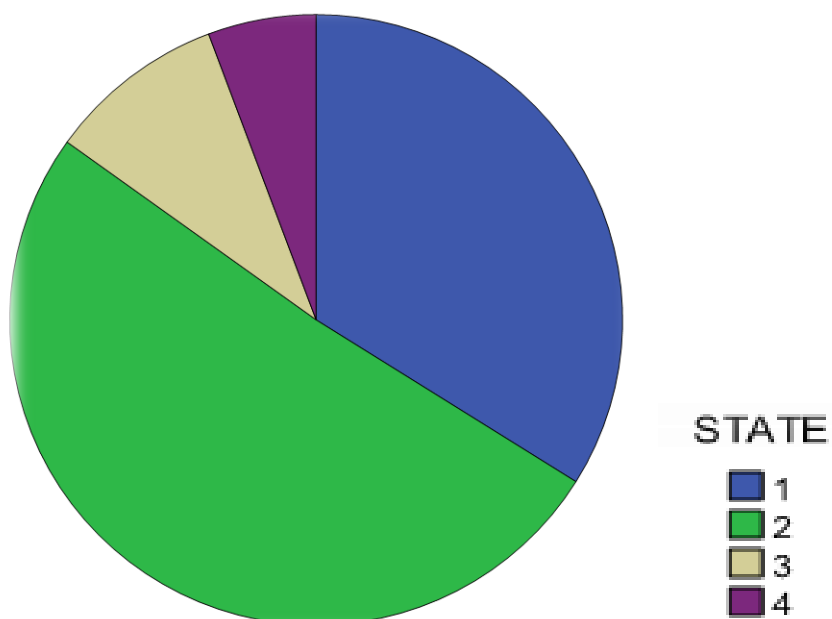
Graph 1. Showing distribution of gender.



Graph 2. Showing distribution of age.



Graph 3. Showing statewise distribution of study subjects.
(1=karnataka, 2=Andhra Pradesh, 3=Tamil Nadu, Kerala=4)



The average stature in the present study is 165.86 cm, (combined males and females), 171.40 cm for males and 160.30 cm for females. With respect to bones of lower limbs there was no significant difference in the lengths of right and left tibia in both males (p-value > 0.05) and females (p-value > 0.05). There was no significant difference in the lengths of right and left fibula in both males (p-value > 0.05) and females (p-value > 0.05). Similarly when the upper limb measurements were analysed there was no significant difference in the lengths of right and left radius in both males (p-value > 0.05) and females (p-value > 0.05) and no significant differences were observed in the lengths of right and left sides of ulna in both males (p-value > 0.05) and females (p-value > 0.05). (Table No. 2a and 2b).

Table 2. Distribution of various anthropometric variables.

Table 2a.

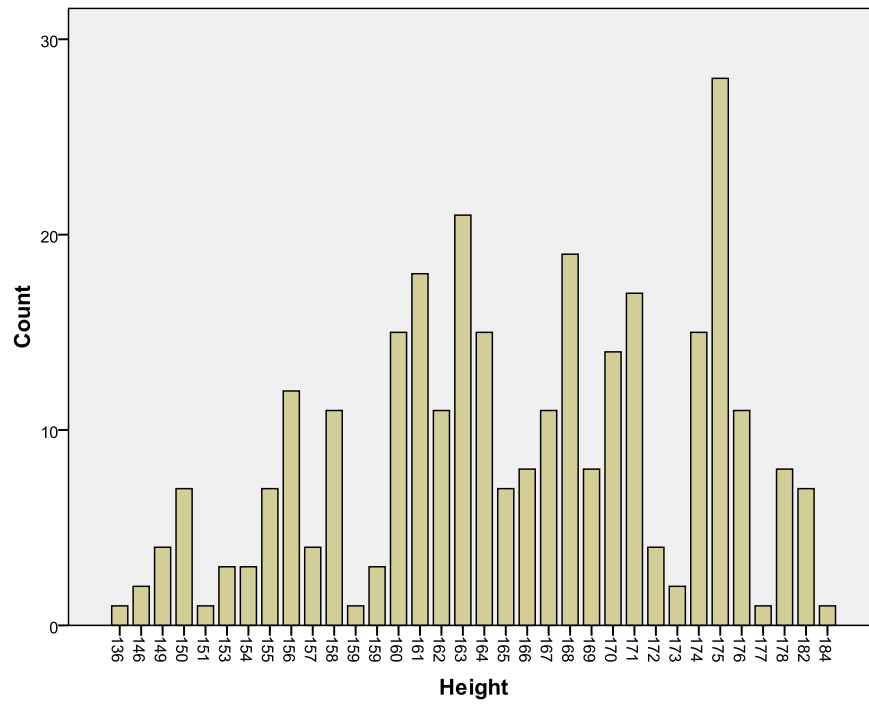
Bone (in cm)		Male \bar{x}		Comparison between right and left sides			Female \bar{x}		Comparison between right and left sides		
		Right	Left	t	DF	p	Right	Left	t	DF	p
LOWER LIMB	Tibia	39.6	39.1	1.637	149	0.104 (NS)	36.6	36.5	1.657	149	0.109 (NS)
	Fibula	39.1	38.7	1.340	149	0.182 (NS)	36.4	36.3	1.328	149	0.187 (NS)
UPPER LIMB	Radius	26.1	25.7	1.623	149	0.103 (NS)	23.8	23.6	1.604	149	0.113 (NS)
	Ulna	27.2	26.9	0.961	149	0.338 (NS)	25.3	25.2	0.982	149	0.389 (NS)

Table 2b.

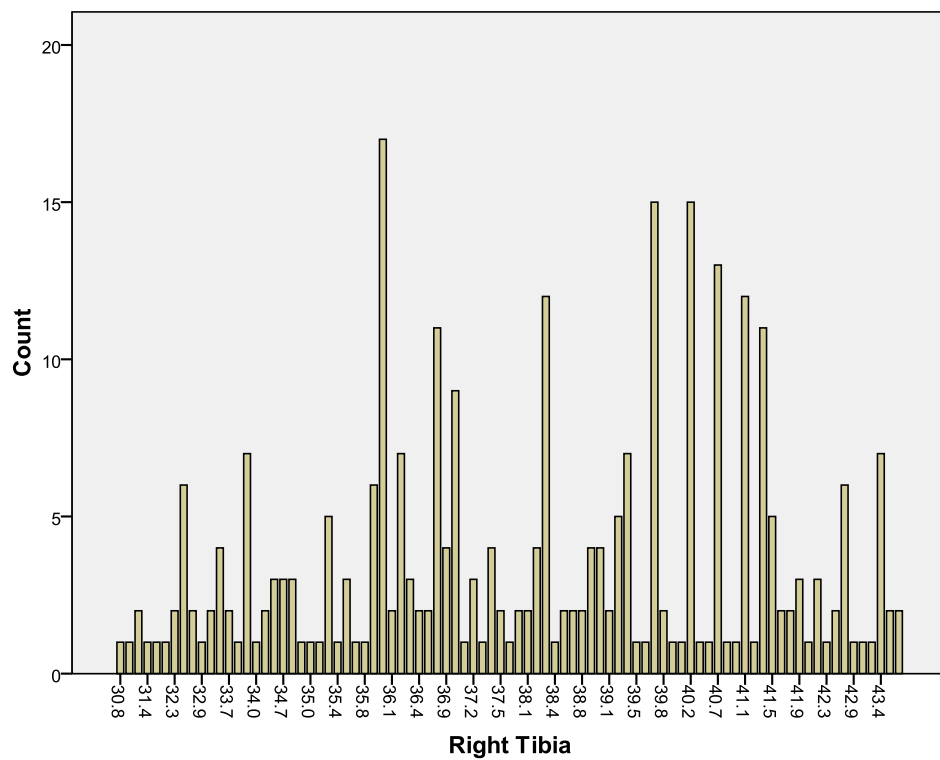
Variables (in cm)		Male			Female			Comparison between Males and Females		
		\bar{x}	SD	SE	\bar{x}	SD	SE	t	DF	p
Standing height (stature)		171.4	5.51	0.45	160.3	6.04	0.49	16.712	298	0.000
LOWER LIMB	Right Tibia	39.6	2.19	0.18	36.6	3.02	0.24	9.655	298	0.000
	Right Fibula	39.2	2.19	0.18	36.8	2.53	0.20	8.641	298	0.000
	Left Tibia	39.1	2.21	0.18	36.5	3.02	0.24	8.494	298	0.000
	Left Fibula	38.7	2.25	0.18	36.7	2.49	0.20	7.139	298	0.000
UPPER LIMB	Right Radius	26.1	1.23	0.10	23.5	1.88	0.15	13.578	298	0.000
	Right Ulna	27.2	1.23	0.10	25.3	1.68	0.14	11.735	298	0.000
	Left Radius	25.7	1.33	0.11	23.8	1.17	0.14	10.757	298	0.000
	Left Ulna	26.9	1.23	0.10	25.3	1.67	0.13	9.475	298	0.000

x=mean height, SD= standard deviation, SE=Standard error, t = student t test, DF =Degrees of freedom, p= Probability test.

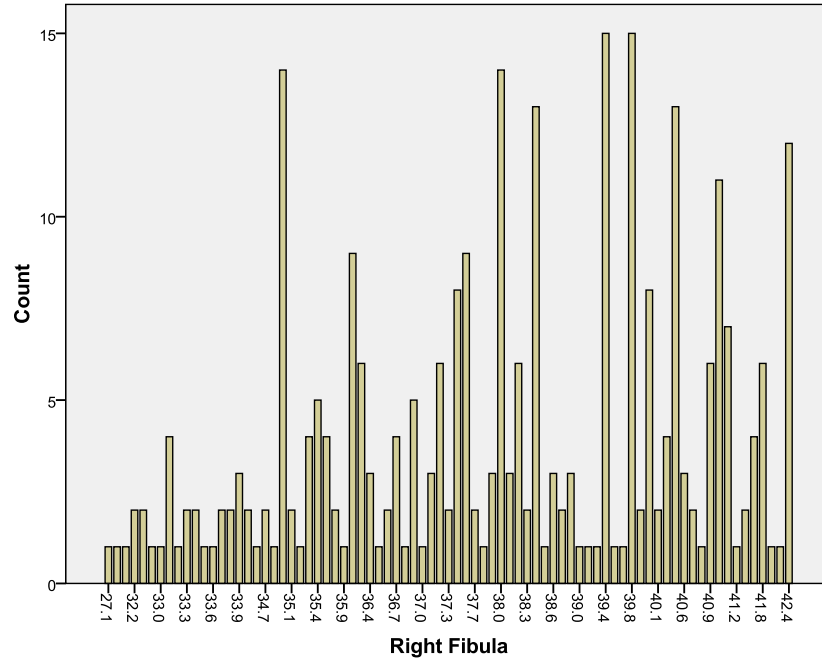
Graph 4. Showing distribution of height.



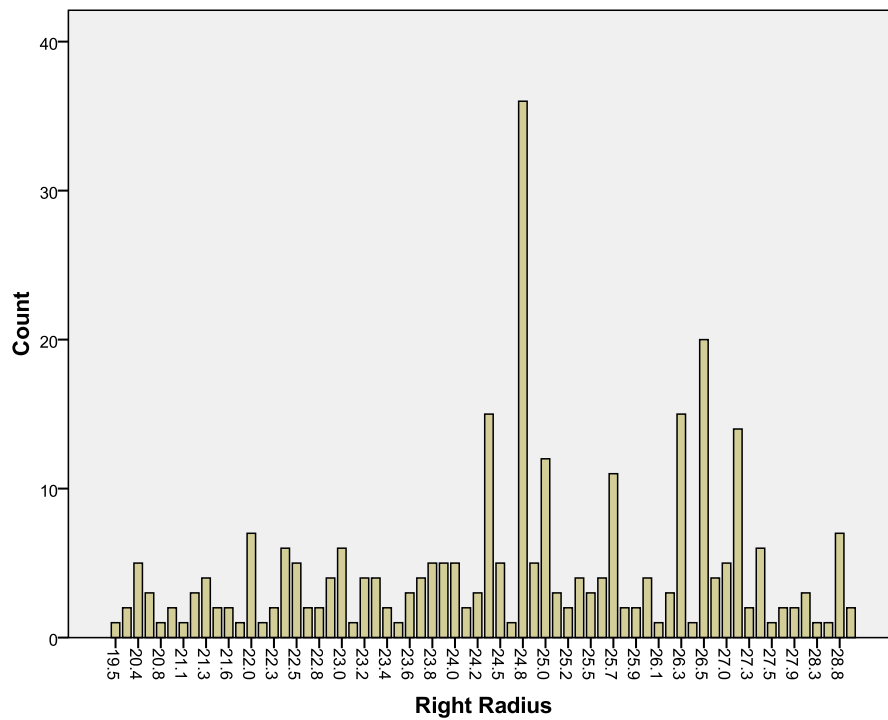
Graph 5. Showing distribution of right Tibia.



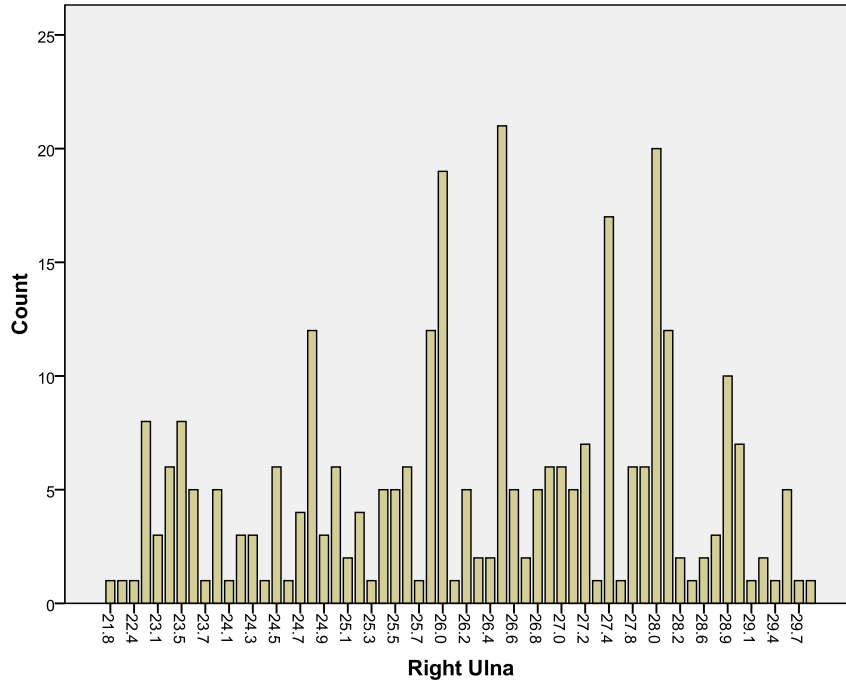
Graph 6. Showing distribution of right Fibula.



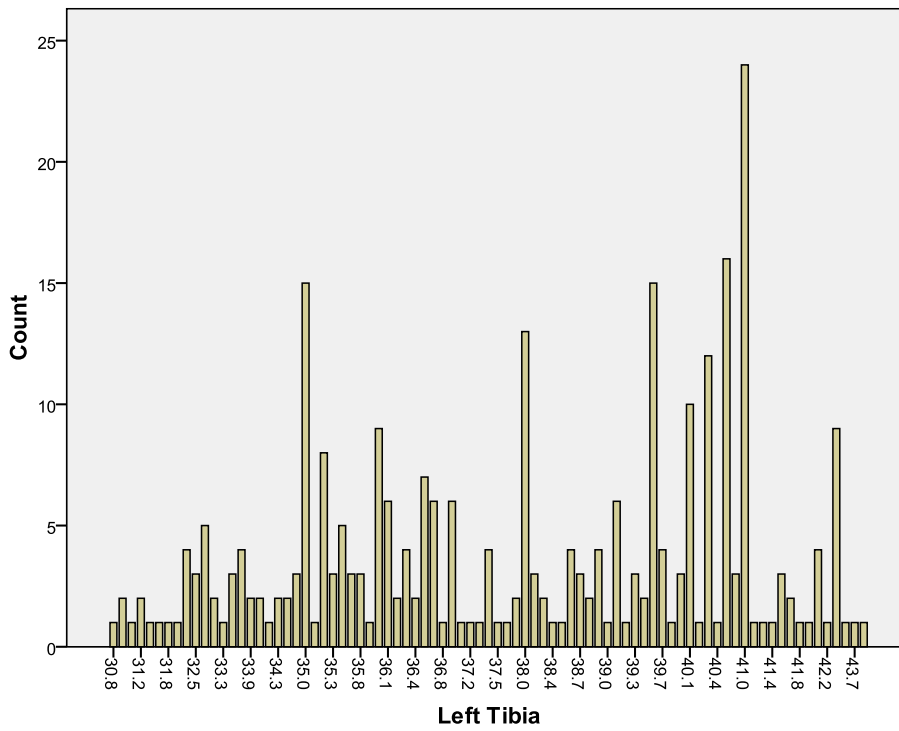
Graph 7. Showing distribution of right Radius.



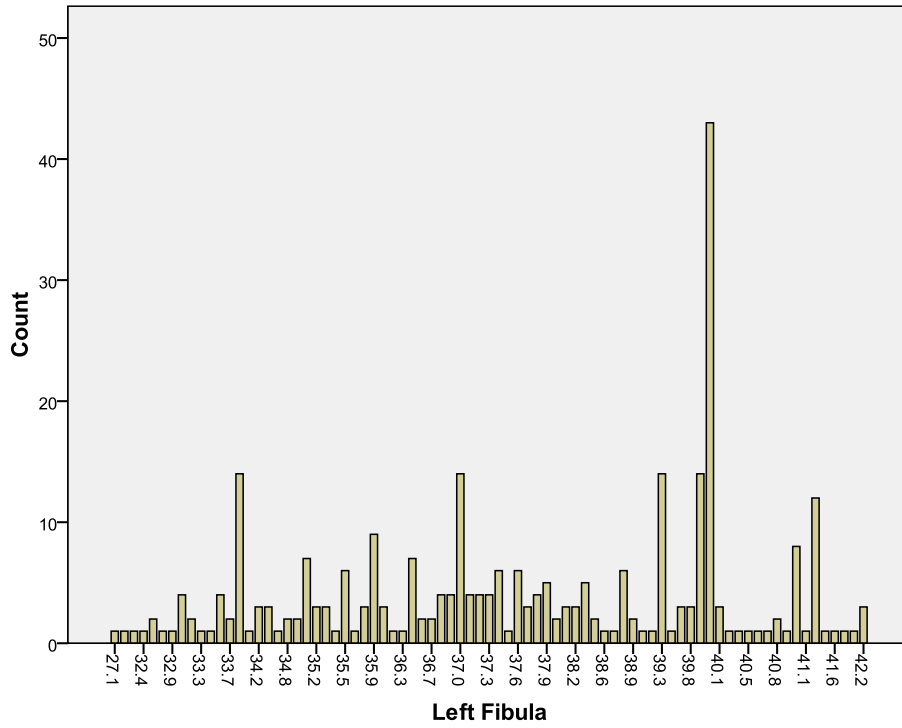
Graph 8. Showing the distribution of right Ulna.



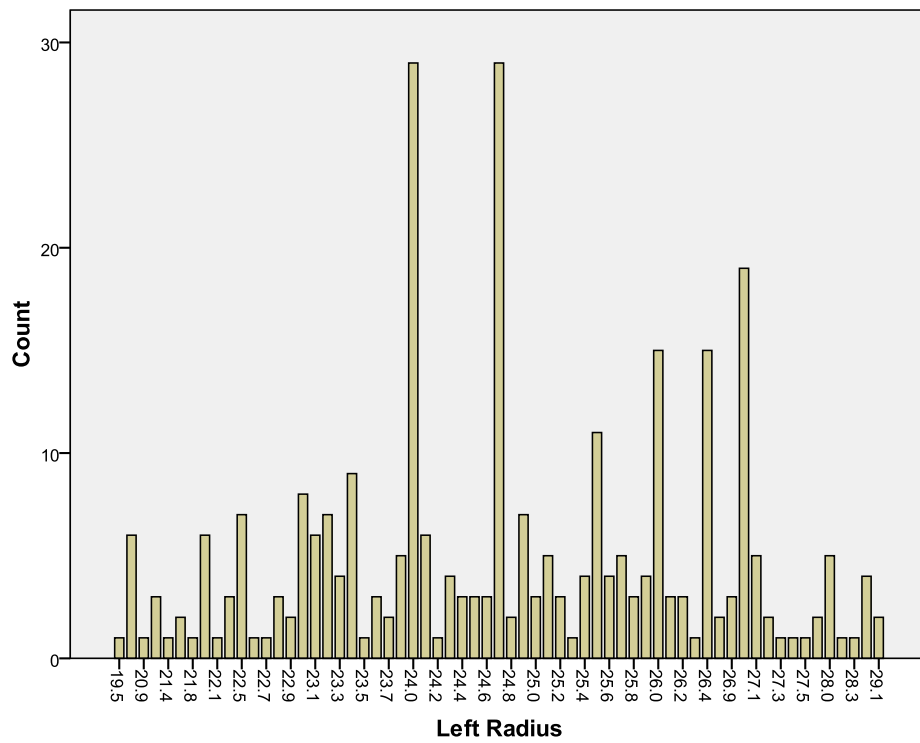
Graph 9. Showing distribution of left Tibia.



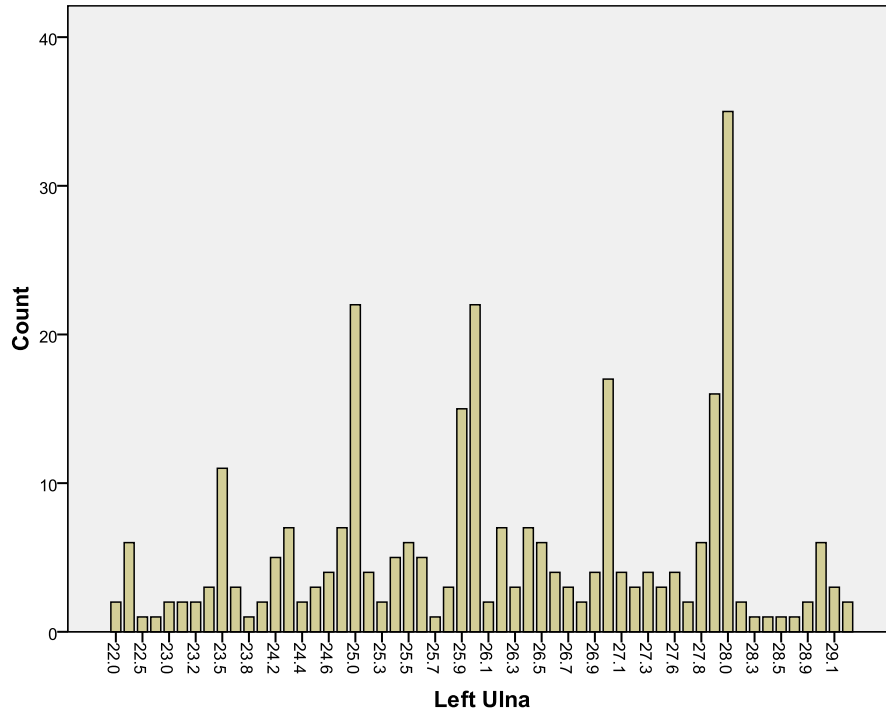
Graph 10. Showing distribution of left Fibula.



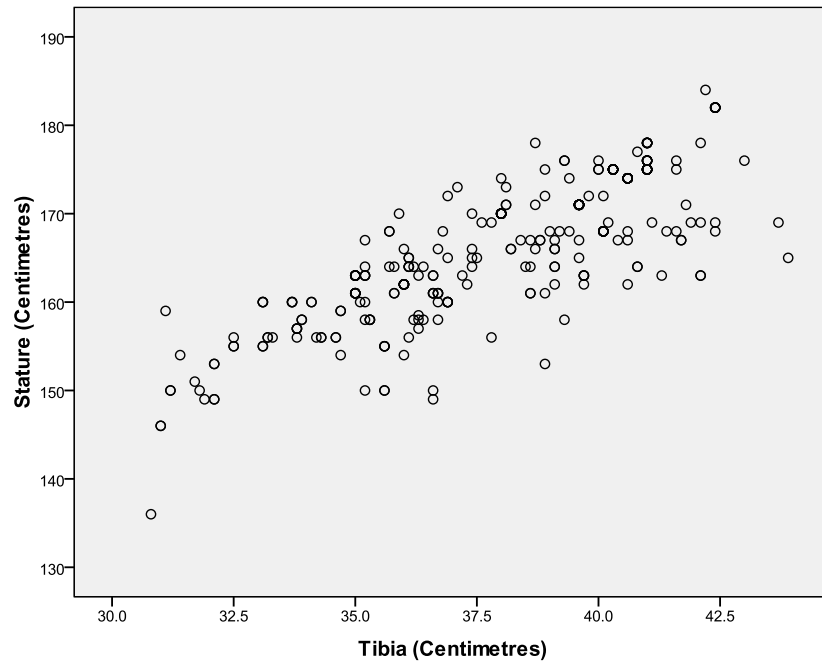
Graph 11. Showing distribution of left Radius.



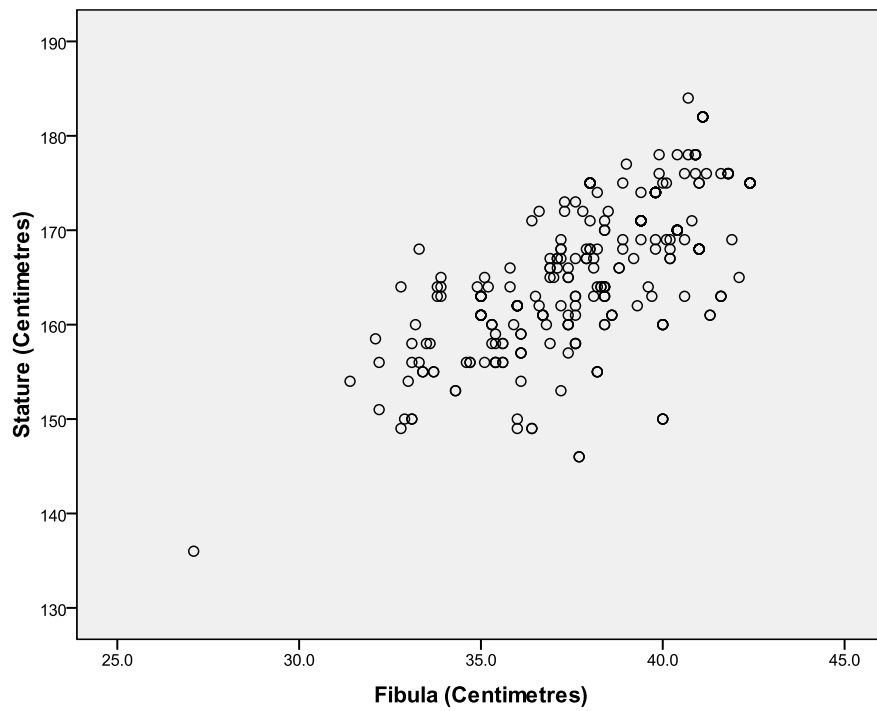
Graph 12. Showing the distribution of left Ulna.



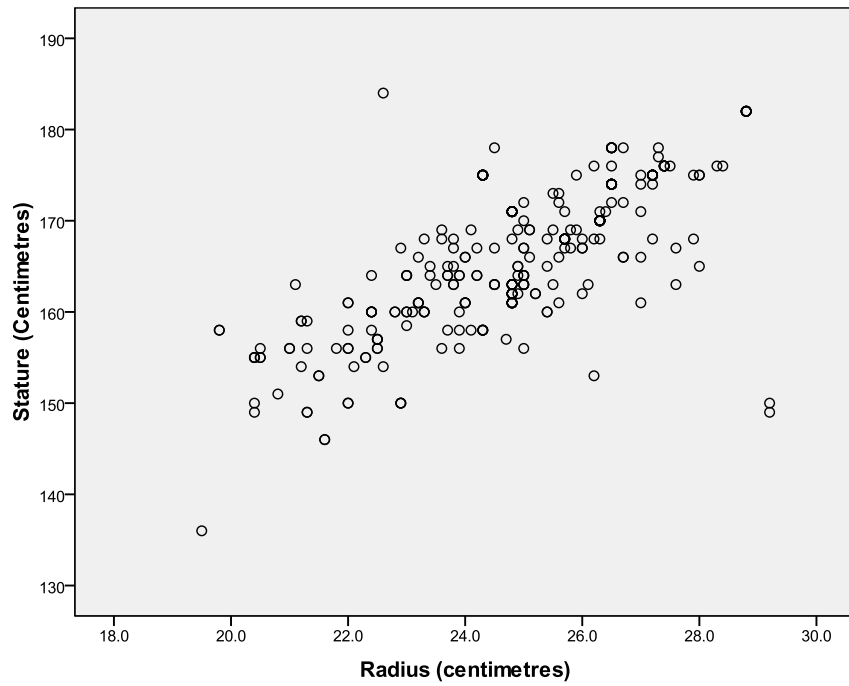
Graph 13. Showing the relationship between Stature and Tibial length.



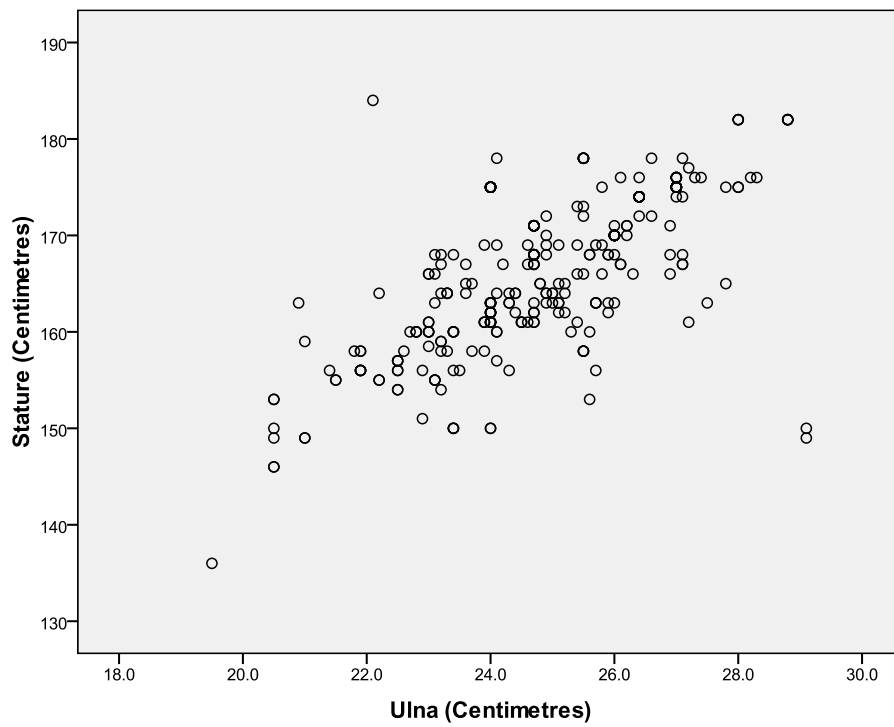
Graph 14. Showing the relationship between Stature and Fibular length



Graph 15. Showing the relationship between Stature and Radial length.



Graph 16. Showing the relationship between Stature and Ulnar length.



All the long bones show a positive correlation (Karl Pearson's) with that of stature.

(Table No.3).

Table 3. Showing correlation coefficient (r) between height and other variables.

Long Bone		Male		Female		Combined	
		r	p	r	p	r	p
LOWER LIMB	Right Tibia	0.820	0.000	0.734	0.000	0.818	0.000
	Right Fibula	0.721	0.000	0.495	0.000	0.694	0.000
	Left Tibia	0.865	0.000	0.751	0.000	0.818	0.000
	Left Fibula	0.738	0.000	0.532	0.000	0.681	0.000
UPPER LIMB	Right Radius	0.570	0.000	0.517	0.000	0.729	0.000
	Right Ulna	0.354	0.000	0.673	0.000	0.713	0.000
	Left Radius	0.588	0.000	0.477	0.000	0.686	0.000
	Left Ulna	0.362	0.000	0.685	0.000	0.682	0.000

A total of 24 simple regression equations were derived in the study, of which 8 were Linear Combined (males and females) regression equations (Table No. 4) and 8 each for every bone for both sexes (Table No. 5).

Table 4. Simple linear combined regression equations.

Long bone		Right sided regression equation ($Y = A+BX$)	Left sided regression equation ($Y = A+BX$)
LOWER LIMB	Tibia	Stature = 82.839 + 2.177.Right Tibia. $r^2 = 0.670$, SEE = 4.62 , 95% CI for b \rightarrow 2 - 2.35	Stature = 81.482 + 2.23.Left Tibia $r^2 = 0.669$, SEE = 4.63, 95% CI for b \rightarrow 2.05 - 2.41
	Fibula	Stature = 85.709 + 2.107.Right fibula $r^2 = 0.481$, SEE = 5.79, 95% CI for b \rightarrow 1.86 - 2.35	Stature = 85.432 + 2.133.Left Fibula $r^2 = 0.464$, SEE = 5.89, 95% CI for b \rightarrow 1.87- 2.39
UPPER LIMB	Radius	Stature= 93.968+2.9 .Right Radius $r^2 = 0.532$, SEE = 5.50, 95% CI for b \rightarrow 2.59-3.21	Stature = 90.02 + 3.061. Left Radius $r^2 = 0.470$, SEE = 5.85, 95% CI for b \rightarrow 2.69 - 3.42
	Ulna	Stature = 81.119+ 3.222.Right Ulna $r^2 = 0.509$, SEE = 5.63, 95% CI for b \rightarrow 2.86 - 3.58	Stature = 80.068 + 3.28.Left Ulna $r^2 = 0.466$, SEE = 5.88, 95% CI for b \rightarrow 2.88 - 3.68

Y=Stature, A=Regression constant, B=Regression coefficient, X=Length of long bone, R= correlation coefficient, SEE= Standard error of estimate, CI= Confidence interval, p= Probability test.

Table 5. Showing regression equations according to sex.

	Female ($Y = A + BX$)	Male ($Y = A + BX$)
LOWER LIMB	Stature = 89.73 + 2.063. Right Tibia $r^2 = 0.673$, $SEE = 3.16$, 95% CI for b → 1.83 – 2.29, $P = 0.000$	Stature = 106.494 + 1.467. Right Tibia $r^2 = 0.539$, $SEE = 4.11$, 95% CI for b → 1.25 – 1.68, $P = 0.000$
	Stature = 100.416 + 1.811. Right Fibula $r^2 = 0.520$, $SEE = 3.83$, 95% CI for b → 1.53 – 2.09, $P = 0.000$	Stature = 116.702 + 1.182. Right Fibula $r^2 = 0.245$, $SEE = 5.26$, 95% CI for b → 0.84 – 1.52, $P = 0.000$
	Stature = 87.295 + 2.150. Left Tibia $r^2 = 0.746$, $SEE = 2.77$, 95% CI for b → 1.95 – 2.35, $P = 0.000$	Stature = 105.352 + 1.503. Left Tibia $r^2 = 0.564$, $SEE = 3.99$, 95% CI for b → 1.29 – 1.72, $P = 0.000$
	Stature = 101.493 + 1.808. Left Fibula $r^2 = 0.545$, $SEE = 3.73$, 95% CI for b → 1.54 – 2.07, $P = 0.000$	Stature = 112.899 + 1.29. Left Fibula $r^2 = 0.283$, $SEE = 5.13$, 95% CI for b → 0.96 – 1.62, $P = 0.000$
UPPER LIMB	Stature = 105.15 + 2.546. Right Radius $r^2 = 0.325$, $SEE = 4.54$, 95% CI for b → 1.95 – 3.14, $P = 0.000$	Stature = 121.185 + 1.661. Right Radius $r^2 = 0.268$, $SEE = 5.18$, 95% CI for b → 1.21 – 2.11, $P = 0.000$
	Stature = 128.1 + 1.588. Right Ulna $r^2 = 0.125$, $SEE = 5.16$, 95% CI for b → 0.91 – 2.27, $P = 0.000$	Stature = 99.168 + 2.416. Right Ulna $r^2 = 0.453$, $SEE = 4.48$, 95% CI for b → 1.98 – 2.84, $P = 0.000$
	Stature = 108.814 + 2.435. Left Radius $r^2 = 0.346$, $SEE = 4.47$, 95% CI for b → 1.89 – 2.97, $P = 0.000$	Stature = 120.072 + 1.688. Left Radius $r^2 = 0.227$, $SEE = 5.32$, 95% CI for b → 1.18 – 2.19, $P = 0.000$
	Stature = 127.7 + 1.622. Left Ulna $r^2 = 0.131$, $SEE = 5.15$, 95% CI for b → 0.94 – 2.30, $P = 0.000$	Stature = 97.585 + 2.473. Left Ulna $r^2 = 0.469$, $SEE = 4.41$, 95% CI for b → 2.04 – 2.90, $P = 0.000$

Y=Stature, A=Regression constant, B=Regression coefficient, X=Length of long bone, R= correlation coefficient, SEE= Standard error of estimate, CI= Confidence interval, p= Probability test.

The multiplication factors for all the four bones on the right (Table No.6a), left (Table No. 6b), and combined (Table No. 6c), for both males and females were derived.

Table 6. Showing multiplication factors.

Table 6a

Right Side								
Gender	Male				Female			
Bone	\bar{x}	SD	SE	Range	\bar{x}	SD	SE	Range
Tibia	4.33	0.15	0.01	3.86/4.72	4.39	0.26	0.02	3.76-5.08
Fibula	4.36	0.17	0.01	4.03/4.70	4.38	0.26	0.02	3.75-5.05
Radius	6.59	0.27	0.02	6.15/8.14	6.84	0.44	0.03	5.1-7.98
Ulna	6.29	0.30	0.02	5.61/8.18	6.35	0.31	0.02	5.56-2.28

Table 6b

Left Side								
Gender	Male				Female			
Bone	\bar{x}	SD	SE	Range	\bar{x}	SD	SE	Range
Tibia	4.38	0.15	0.01	3.87-4.74	4.40	0.26	0.02	3.76-5.11
Fibula	4.39	0.18	0.01	4.04-4.79	4.44	0.25	0.02	3.75-5.02
Radius	6.67	0.29	0.02	6.17-8.33	6.75	0.40	0.03	5.12-7.80
Ulna	6.34	0.30	0.02	5.83-8.21	6.37	0.30	0.02	5.54-7.21

Table 6c

	Right Side			Left Side			Combined	
	Male	Female	Combined	Male	Female	Combined	Male	Female
Tibia	4.33	4.39	4.36	4.38	4.40	4.39	4.36	4.40
Fibula	4.36	4.38	4.37	4.39	4.44	4.41	4.37	4.41
Ulna	6.59	6.84	6.71	6.67	6.75	6.71	6.64	6.80
Radius	6.29	6.35	6.32	6.34	6.37	6.35	6.33	6.35

SD=Standard deviation, SE=Standard error.

The average error was found to be insignificant in both males as well as females (< 1 cm, $p > 0.05$), when the average stature estimated by multiplication factor was compared with measured average living stature (Table No. 7).

Table 7. Combined Estimate using mean multiplication factors.

(in cm)		Mean	SD	SE	Range
LOWER LIMB	Right Tibia	166.3	13.16	0.76	134.29-190.87
	Right Fibula	166.2	11.55	0.66	118.43-185.29
	Left Tibia	166.1	12.93	0.74	135.21-192.72
	Left Fibula	166.3	11.30	0.65	119.51-186.1
UPPER LIMB	Right Radius	166.4	13.55	0.78	130.84-195.93
	Right Ulna	166.2	11.23	0.65	137.78-187.70
	Left Radius	166.2	12.07	0.69	130.84-195.26
	Left Ulna	166.1	10.60	0.61	139.7-189.23

SD= Standard deviation, SE= Standard error, Actual average stature =165.86 cm.

When the estimated stature by derived regression equations was compared with estimated stature by multiplication factors, the average difference was <1cm. This difference was statistically insignificant ($p>0.05$). Thus, the derived equations and multiplication factors are equally valid. (Table No. 8).

Table 8. Showing comparison between the estimated stature by regression equations and estimated stature by multiplication factors.

Long bone		Mean difference between the estimated stature by regression equation and as estimated by multiplication factors.	SD	SE	Paired t	p
LOWER LIMB	Right Tibia	0.44	8.04	0.46	0.946	0.345
	Right Fibula	0.36	8.31	0.48	0.756	0.450
	Left Tibia	0.28	7.86	0.45	0.610	0.542
	Left Fibula	0.47	8.28	0.48	0.938	0.349
UPPER LIMB	Right Radius	0.48	9.45	0.54	0.896	0.371
	Right Ulna	0.31	7.87	0.45	0.671	0.503
	Left Radius	0.36	8.78	0.51	0.709	0.479
	Left Ulna	0.24	7.79	0.45	0.530	0.596

Actual Mean height (300) = 165.86 cm, SD=Standard deviation, SE=Standard error, p=Probability test.

When the derived regression equations were applied on a fresh sample of south Indian population (sample size =100) the average difference between actual and calculated height was <1cm in both males and females. This difference was statistically insignificant ($p>0.05$). Thus, the derived equations are valid. (Table No. 9)

Table 9. Validation of the derived regression equations on fresh sample of south Indians (n=100).

Table 9 a. For males.

Long bone		Mean difference between actual height and estimated height by regression equations (in cm)	SD	SE	Paired t	p
LOWER LIMB	Right Tibia	0.09	9.48	0.77	0.186	0.852
	Right Fibula	0.34	9.61	0.78	0.615	0.540
	Left Tibia	0.01	9.70	0.79	0.019	0.985
	Left Fibula	0.35	9.98	0.81	0.609	0.544
UPPER LIMB	Right Radius	0.15	8.12	0.66	0.278	0.782
	Right Ulna	0.21	7.72	0.63	0.343	0.732
	Left Radius	0.13	8.87	0.72	0.218	0.828
	Left Ulna	0.29	7.82	0.64	0.469	0.640

Actual mean Height of Males=171.4 cm, SD= standard deviation, SE =standard error, p= Probability test.

Table 9 b. For Females.

Long bone		Mean difference between actual height and estimated height by regression equations (in cm)	SD	SE	Paired t	p
LOWER LIMB	Right Tibia	0.40	9.73	0.79	0.882	0.379
	Right Fibula	0.41	9.59	0.78	0.522	0.603
	Left Tibia	0.32	9.61	0.78	0.662	0.509
	Left Fibula	0.51	9.24	0.75	0.807	0.421
UPPER LIMB	Right Radius	0.46	11.02	0.90	0.847	0.399
	Right Ulna	0.33	7.98	0.65	0.512	0.609
	Left Radius	0.31	10.13	0.83	0.123	0.534
	Left Ulna	0.46	7.81	0.63	0.729	0.467

Actual mean Height of females=160.3 cm, SD= standard deviation, SE =standard error, p= Probability test.

The derived multiplication factors were applied on a fresh sample of south Indian population (sample size =100) the average difference between actual and calculated height was <1cm in both males and females. This difference was statistically insignificant ($p>0.05$). Thus, the derived multiplication factors are valid. (Table No.10)

Table 10. Validation of the derived Multiplication Factors on fresh sample of south Indians (n=100).

Table 10 a. For males.

Long bone		Mean difference between actual height and estimated height by multiplication factors (in cm)	SD	SE	Paired t	p
LOWER LIMB	Right Tibia	0.39	7.19	0.39	0.866	0.467
	Right Fibula	0.35	7.33	0.46	0.896	0.587
	Left Tibia	0.29	6.89	0.42	0.650	0.673
	Left Fibula	0.39	7.27	0.49	0.878	0.458
UPPER LIMB	Right Radius	0.44	8.47	0.53	0.746	0.385
	Right Ulna	0.38	8.86	0.47	0.881	0.754
	Left Radius	0.36	8.76	0.55	0.899	0.688
	Left Ulna	0.21	8.73	0.40	0.750	0.489

Actual mean Height of Males=171.4 cm, SD= standard deviation, SE =standard error, p= Probability test.

Table 10 b. For Females.

	Long bone	Mean difference between actual height and estimated height by multiplication factors (in cm)	SD	SE	Paired t	p
LOWER LIMB	Right Tibia	0.55	8.44	0.53	0.905	0.295
	Right Fibula	0.47	8.61	0.59	0.786	0.354
	Left Tibia	0.44	8.96	0.58	0.689	0.489
	Left Fibula	0.55	8.38	0.56	0.982	0.259
UPPER LIMB	Right Radius	0.58	9.75	0.68	0.838	0.282
	Right Ulna	0.43	7.97	0.54	0.699	0.455
	Left Radius	0.47	8.88	0.64	0.828	0.375
	Left Ulna	0.39	8.99	0.66	0.753	0.486

Actual mean Height of females=160.3 cm, SD= standard deviation, SE =standard error, p= Probability test.

STATURE ESTIMATION FROM PERCUTANEOUS LONG BONE LENGTHS BY FORMULATED REGRESSION FORMULA.

We have estimated stature amongst the south Indian students of JN medical College, Belgaum, age of the subjects ranging between 20 to 30 years. The students are admixture of population from south India (Karnataka, Andhra Pradesh, Kerala and Tamil Nadu) . Average stature seen in our study is 171.40 cm in males and 160.30 cm in females with an average error of less than 1cm. These findings correlate with that of observations made by Mukta Rani, Tyagi A.K, Verma S.K, Kohli A⁵¹ (2004) who estimated the stature in the students of Delhi of same age group and found it to be 169.5cm in male and 159.5cm in female. Our estimated stature also correlates well with that of study by Bhavana S and S. Nath⁹(2009) who estimated stature of male and female Shia Muslims of Delhi among the same age group. Their estimated stature was 167.66 cm for males and 154.40 cm for females. However as shown in table no.11 stature estimated in our study does not match with stature estimated by other workers in different states of India, in fact the average height in males is more than that in other studies, this could be due to recent improvement in the dietary factors. Since Anthropometric characteristics have direct relationship with sex, shape and form of an individual and these factors are intimately linked with each other and manifestation of the internal structure and tissue components which in turn are influenced by environmental and genetic factors. It is a fact especially familiar not only to anatomists but also to artists that trunks and limbs exhibit consistent ratios among themselves and relative to total height. The ratios are linked to age, sex and race.^{9,13,14}

Table 11. The values of Stature reported from different parts of India and from present study.

SL NO	AUTHOR	MEAN STATURE (in cm)	RANGE (in cm)	POPULATION (RACE/REGION)	CORRELATION WITH CURRENT STUDY
1	Pan.N ²⁴ (1924)	162.0	-----	Hindus	No
2	B.S.Siddiqui and Shah ¹⁵ (1944)	163.6	148.7 – 168.7	Punjabis	No
3	Singh and Sohal ⁶³ (1952)	163.0	147.2-182.6	Punjabis	No
4	Bhargava and Kher ⁴⁷ (1961)	160.0	146.0 – 177.8	Bhils (M.P)	No
5	Bhargava and Kher ⁴⁷ (1961)	161.0	153.0 – 179.8	Barelas (M.P)	No
6	Athawale ¹⁸ (1963)	163.1	149.02 – 177.8	Western Maharashtra	No
7	Kolte and Bansal ¹⁹ (1974)	Male 165.7 Female 147.7	–	Marathwada	No
8	Mohanty ¹¹ (1998)	Male 162.0 Female 152.0	–	Orissa.	No
9	Mukta Rani, A.K Tyagi, S.K Verma, and A Kohli ⁵¹ (2004)	Male 169.5 Female 159.5	–	Delhi.	Yes
10	Bhavna and Nath ⁹ (2009)	Male 167.66 Female 154.40	151.0 –180 143.9 –172.9	Delhi.	Yes
11	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	Male 171.40 Female 160.30	152.3-184 138-167	South India.	-

In present study we derived a total set of 24 simple regression equations, of which 8 are combined for both the sides (Table no.3) and 8 each for every bone(Tibia, Fibula, Radius, Ulna) for both males and females (Table no.5). South India is a peninsula predominantly encompassing 4 states, viz Karnataka, Andhra Pradesh, Tamil Nadu and Kerala which comprise 20 % of total Indian soil and most of the people are of Dravidian decent. Hence the current study represents the anthropological data of Dravidian race. After substituting percutaneous tibial length of Indian population in Allbrook's derived regression equation⁶⁴, the stature comes out to be 166.05 cm for south Indian male population.

Above analysis indicates that the regression formula derived for estimating the stature in British population is not suitable to estimate the stature in south Indian population. In 1899 Pearson estimated stature through regression equation as 169.2cm in male and 159.7cm in female²³, which differs from our findings particularly where female stature is concerned. In 1976 Kate and Muzumdar expressed similar view after comparing the derived regression equation for Maharashtrian and Punjabis with that of Pearson's regression formula derived from English bone.¹² They stated that Pearson's regression equation does not give exact results in Indian population. However Pearson calculated stature in French cadavers, that too only from right tibial length only. While comparing the estimated stature of 48 north Chinese males with that of Pearson's regression formula, Stevenson P.H in 1929 has already suggested that Better results from regression formula will be obtained by applying a specific formula to a specific race is than using a single formula applying for all the races.³¹ This statement is true with reports prepared by Trotter and Gleser in 1958 who studied group of American whites, Negroes, Mongolian and Mexicans with different formulae to derive the estimate of stature.¹⁶ Similarly this is true with observations

made by Yayim yili in 1996 wherein he observed that application of formulae derived for African, European and Asian populations led to suboptimal values for Turkish population.³⁷

Mendes Correa³², Telkka A³³, GlaisterJ³⁴ and Bidmos M.A⁶⁵ observed that documented cadaver length was significantly higher than the estimated living stature. But our study is devoid of such errors as we have directly carried out the study in living subjects rather than cadavers and the stature so estimated from percutaneous measurement of bone lengths was directly compared with average measured stature in the living, however Allbrook DC⁶⁴ compared both estimated stature derived from length of dried tibia and from the average percutaneous tibial length and found that there was no significant difference between them.

Our study shows positive correlation between stature as measured by regression equations with that of the actual height amongst the south Indian population which is similar to observations made by Celbis⁴¹, Gunay⁴¹, and Sam⁴¹ (Table No. 12).

The regression equations when applied to a fresh south Indian sample showed a mean difference between actual height and estimated height is less than 1 cm ($p>0.05$). Therefore the derived regression equations are valid and applicable to the South Indian population (Table No. 9). However the derived regression equations for the south Indian population do not match with any of the other races, nations or the religions studied, as these are individually different (Table No. 13,14,15 and 16). This finding substantiates the views expressed by other workers that, state wise and population wise, different regression formulae are required for estimation of stature.

Table 12. Correlation coefficient values from other studies and present study.

SEX	BONE	CORRELATION COEFFICIENT (AUTHOR)	CURRENT STUDY CORRELATION COEFFICIENT
Male	Ulna	0.62 (Celbis) ⁴¹	0.577
	Radius	0.64 (Celbis) ⁴¹	0.699
	Tibia	0.72 (Gunay) ⁴¹	0.844
	Fibula	0.76 (Sam) ⁴¹	0.733
Female	Ulna	0.76 (Celbis) ⁴¹	0.744
	Radius	0.85 (Celbis) ⁴¹	0.722
	Tibia	0.63 (Gunay) ⁴¹	0.833
	Fibula	0.64 (Sam) ⁴¹	0.712

Table 13. Regression formula worked out by various authors for Tibia in different population (race/ region) and the present study.

SL NO	AUTHOR	POPULATION (RACE/ REGION)	MALE EQUATION (S=A+BT)	FEMALE EQUATION (S=A+BT)	CORRELATION (With current study)
1	Pearson ²³ (1899)	British	S= 78.664 + 3.378T	S= 74.774 + 2.325T	No
2	Trotter and Gleser ¹⁶ (1952)	American whites	S= 78.62 + 2.52T	S= 61.53 + 2.90T	No
3	Trotter and Gleser ¹⁶ (1952)	American blacks	S= 86.02 + 2.19T	S= 72.65 + 2.45T	No
4	Bass ³ (1994)	Caucasoid	S= 81.93 +2.42T	S= 61.53 +2.90T	No
5	Bass ³ (1994)	Negroid	S= 85.36 +2.19T	S= 72.56 +2.45T	No
6	Yayim yili ³⁷ (1996)	Turkish	S= 71.2 + 2.7T	S= 92.4 + 1.9T	No
8	Anand and Nath ⁶⁶ (1990)	Uttar Pradesh	S= 114.81 + 0.26T	-----	No
9	Nath and Krishan ⁶⁷ (1990)	Delhi	S= 83.53 + 1.97T	-----	No
10	N.K Mohanty ¹¹ (1998)	Orissa	S= 22.8325 + 3.75T	S= 27.3032 +3.5587T	No
11	Mukta Rani, A.K Tyagi, S.K Verma, and Kohli ⁵¹ (2004)	Delhi	S(Rt)= 104.971+1.85T S(Lt)= 105.324+1.83T	S(Rt)= 107.100+1.70T S(Lt)= 107.199+1.69T	No
12	Bhavana and SurinderNath ¹⁰ (2006)	Jat(Sampla), Haryana	S= 109.40 + 1.34T	-----	No
13	Bhavana and SurinderNath ¹⁰ (2006)	Brahmin Sampla , Haryana	S= 100.02 +1.57T	-----	No
14	Bhavana and SurinderNath ⁹ (2009)	Shia Muslims, Delhi	S= 84.74 + 2.27T	S= 75.66 + 2.34T	No
15	Arun Kumar Agnihotri, SmitaKachhwaha, VandnaJowaheer, Ashok Pratap Singh ⁵² (2009)	Indo Mauritian	S= 21.0 + 2.83T	-----	No
16	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	South Indian	(Rt)S= 106.494+1.46T (Lt)S= 105.352+1.50T	(Rt)S= 89.73+2.063T (Lt)S= 87.295 +2.150T	----

S=Stature, A= Regression constant, B= Regression coefficient, T= Percutaneous length of Tibia.

Table 14. Regression formula worked out by various authors for Fibula in different population (race/ region) and the present study.

SL NO	AUTHOR	POPULATION (RACE/ REGION)	MALE EQUATION (S=A+BT)	FEMALE EQUATION (S=A+BF)	CORRELATION (With current study)
1	Bass ³ (1994)	Caucasoid	S= 75.50 +2.60F	S= 59.61+2.93F	No
2	Bass ³ (1994)	Negroid	S= 80.07+2.34F	S= 70.90 +2.49F	No
3	Bass ³ (1994)	Mongoloid	S= 80.56+2.40F	-----	No
4	Kaur ⁶⁸ (1996)	Rajput Sirmour, Himachal pradesh.	S= 82.19+ 2.26F	S = 70.73+ 2.45F	No
5	Sethi and Nath ⁶⁹ (2001)	Punjabi, Delhi	S = 86.83+ 1.93F	-----	No
6	Sethi and Nath ⁶⁹ (2001)	Jain, Delhi	S = 73.92+ 2.26F	-----	No
7	Kaur ⁷⁰ (1998)	Sikh, Delhi	S = 85.10+ 2.08F	S = 81.88+ 1.99F	No
8	Jain ⁷¹ (1999)	Jains, Delhi	S = 88.92 + 1.87F	S = 85.50+ 2.15F	No
9	Bhavana and Surinder Nath ¹⁰ (2006)	JatSampla, Haryana	S = 98.45 + 1.56F	-----	No
10	Bhavana and Surinder Nath ¹⁰ (2006)	Brahmin Sampla, Haryana	S = 107.29 + 1.29F	-----	No
11	Bhavana and Surinder Nath ⁹ (2009)	Shia Muslim Delhi	S = 79.35+ 2.29F	S = 72.21+ 2.30F	No
12	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	South India	(Rt)S= 116.702+1.182F (Lt) S=112.899+1. 29F	(Rt) S= 100.416 +1.811F (Lt)S=101.493 +1.808F	---

S=Stature, A= Regression constant, B= Regression coefficient, F= Percutaneous length of the Fibula.

Table 15. Regression formula worked out by various authors for Ulna in different population (race/ region) and the present study.

SL NO	AUTHOR	POPULATION (RACE/REGION)	MALE EQUATION (S=A+BU)	FEMALE EQUATION (S=A+BU)	CORRELATION (With current study)
1	Bass ³ (1994)	Caucasoid	S= 75.55+3.76U	S= 57.76+4.27U	No
2	Bass ³ (1994)	Mongoloid	S= 77.45 +3.48U	-----	No
3	Bass ³ (1994)	Negroid	S= 82.77+3.20U	S= 75.38 +3.31U	No
4	Celbis ⁴¹ (2005)	Turkish	S= 89.01 +3.054U	S= 57.32 +4.217U	No
5	Arun Kumar Agnihotri, Smita Kachhwaha, Vandna Jowaheer, Ashok Pratap Singh ⁵² (2009)	Indo Mauritian	S= 60.4+4.13U	-----	No
6	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	South Indian	(Rt)S= 99.168+2.416U (Lt)S= 97.585+2.473U	(Rt)S= 128.1 +1.588U (Lt)S= 127.7 +1.622U	—

S=Stature, A= Regression constant, B= Regression coefficient, U= Percutaneous length of Ulna.

Table 16. Regression formula worked out by various authors for Radius in different population (race/ region) and the present study.

SL NO	AUTHOR	POPULATION (RACE/REGION)	MALE EQUATION (S=A+BR)	FEMALE EQUATION (S=A+BR)	CORRELATION (with current study)
1	Bass ³ (1994)	Caucasoid	S= 79.42+3.79 R	S= 54.93+ 4.74 R	No
2	Bass ³ (1994)	Negroid	S= 85.43 +3.32R	S= 71.79 + 3.67R	No
3	Bass ³ (1994)	Mongoloid	S= 82.00+3.54 R	-----	No
4	Celbis ⁴¹ (2005)	Turkish	S= 87.23 +3.367R	S= 53.99+4.731R	No
5	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	South Indian	(Rt)S= 121.185+1.661R (Lt)S= 120.072+1.688R	(Rt)S= 105.15 +2.546R (Lt)S= 108.814 +2.435R	---

S=Stature, A= Regression constant, B= Regression coefficient, R= Percutaneous length of the Radius.

**STATURE ESTIMATION FROM PERCUTANEOUS BONE
LENGTH BY USING FORMULATED MULTIPLICATION
FACTOR.**

Being the second most common method in practice, the stature so estimated from percutaneous bone length with the help of formulated multiplication factor is compared with living stature. The average multiplication factor is calculated in this study as per method proposed by Pan²⁴ in 1924. According to Lal C.S and Lala J.K¹⁷ Multiplication factor (M.F) remains more or less constant in age group of 18-21years. In present study similar age group was selected for study. Our values of M.F are different from those observed from other studies (Table No. 17, 18, 19 and 20) . Thus, the results obtained from resident of one province are not applicable to those of another, stressing the importance of developing different multiplication factors for different population groups. B.S. Nat¹⁴; Siddiqui and Shah¹⁵ and; Singh B and Sohal H.S⁶² also expressed the same views after estimating stature in Punjabis. According to Trotter and Gleser¹⁶ world population is getting taller and therefore relationship between height and length of long bones is changed and fresh formulae or M.F are needed for each generation. Accordingly our present study has provided fresh multiplication factors for South Indians and these are different from other similar studies.

The multiplication factors when applied to a fresh south Indian sample (n=100) showed a mean difference between actual height and estimated height is less than 1 cm ($p>0.05$). Therefore the derived multiplication factors are valid and applicable to the South Indian population (Table No. 10).

The average error was found to be <1cm in both males and in females ($p>0.05$) when average stature estimated by multiplication factor was compared with the stature estimated using regression equations (table no.7). Hence multiplication factors can be used as second line formulae for estimation of stature.

Table 17. Multiplication factor for tibia from Percutaneous Tibial length for different population (race/ region) and the present study.

SL NO	AUTHOR	POPULATION (RACE/ REGION)	MULTIPLICATION FACTORS(MF= $\Sigma S/\Sigma T$)		CORRELATION (with present study)
			Male	Female	
1	Pan ²⁴ (1924)	Calcutta	4.49	4.46	No
2	Nat ⁶ (1931)	Lucknow	4.48	-	No
3	Mehtha and Thomas ⁶ (1936)	Mysoreans	4.2	4.39	No
4	Siddiqui and Shah ¹⁵ (1944)	Punjab	4.2	-	No
5	Duggal and Nath ⁷² (1986)	Lodha / West Bengal	4.23	4.27	No
6	Duggal and Nath ⁷² (1986)	Munda /West Bengal	4.17	4.19	No
7	Anand and Nath ⁶⁶ (1990)	Rajput Garhwal/U.P	4.52	4.46	No
8	Nath, Rajni and Chhibber ⁷³ (1990)	Punjabi / Delhi	-	4.46	No
9	Bhavana and SurinderNath ⁹ (2009)	Shia Muslims / Delhi	4.60	4.59	No
10	Dr Vinay and Dr Manjulabai K.H.(2011, Present Study)	South Indians	4.36	4.395	-----

ΣS =Summation Stature, ΣT =Summation of Tibial Length.

Table 18. Multiplication factor for Fibula from Percutaneous length for different population (race/ region) and the present study.

SL NO	AUTHORS	POPULATION (RACE/REGION)	MULTIPLICATION FACTORS (MF= $\sum S/\sum F$)		CORRELATION (with current study)
			Males	Females	
1	Pan ²⁴ (1924)	Hindus of Bengal, Bihar and Orissa States	4.43	4.46	No
2	Nat ⁶ (1931)	Lucknow	4.48	-	No
4	Mehta and Thomas ⁶ (1936)	Mysoreans	4.44	4.55	No
3	Siddiqui and Shah ¹⁵ (1944)	Punjab	4.4	-	No
5	Nath and Rautray ⁷⁴ (1996)	Jat Churu, Rajasthan	4.11	4.13	No
6	Kaur ⁶⁸ (1996)	Rajput (Sirmour), Himachal Pradesh.	4.45	4.44	No
7	Kaur ⁷⁰ (1998)	Sikh Delhi	4.16	4.15	No
8	Jain ⁷¹ (1999)	Jains Delhi	4.44	4.43	No
9	Bhavana and SurinderNath ¹⁰ (2006)	Jat Sampla, Haryana	4.18	4.16	No
11	Bhavana and SurinderNath ¹⁰ (2006)	Shia Muslim , Delhi	4.32	4.33	No
12	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	South Indians	4.37	4.41	-----

$\sum S$ =Summation Stature, $\sum F$ =Summation of Fibular Length.

Table 19. Multiplication factor for Radius from percutaneous length for different population (race/ region) and the present study.

SL NO	AUTHORS	POPULATION (RACE/REGION)	MULTIPLICATION FACTORS(MF= $\sum S/\sum R$)		CORRELATION (with current study)
			Males	Females	
1	Pan ²⁴ (1924)	Hindus of Bengal, Bihar and Orissa States	6.00	6.00	No
2	Nat ⁶ (1931)	Lucknow	6.9	---	No
3	Mehta and Thomas ⁶ (1936)	Mysoreans	6.01	6.24	No
4	Siddiqui and Shah ¹⁵ (1944)	Punjab	6.3	---	No
5	Nath and Rautray ⁷⁴ (1996)	JatChuru, Rajasthan	6.12	6.10	No
6	Kaur ⁶⁸ (1996)	Rajput, Sirmour, Himachal Pradesh.	6.14	6.12	No
7	Kaur ⁷⁰ (1998)	Sikh, Delhi	6.09	6.05	No
8	Jain ⁷¹ (1999)	Jains, Delhi	6.02	6.00	No
9	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	South Indians	6.33	6.35	-

$\sum S$ =Summation Stature, $\sum R$ =Summation of Radius Length.

Table 20. Multiplication factor for Ulna from percutaneous length for different population (race/ region) and the present study.

SL NO	AUTHORS	POPULATION (RACE/REGION)	MULTIPLICATION FACTORS(MF= $\sum S/\sum U$)		CORRELATION (with current study)
			Males	Females	
1	Pan ⁶ (1924)	Hindus of Bengal, Bihar and Orissa States	6.78	6.70	No
2	Nat ⁶ (1931)	Lucknow	6.3	---	No
3	Mehta and Thomas ⁶ (1936)	Mysoreans	6.4	6.85	No
4	Siddiqui and Shah ¹⁵ (1944)	Punjab	6.0	---	No
5	NathS and Rautray ⁷⁴ (1996)	Jat Churu, Rajasthan	6.88	6.80	No
6	Kaur ⁶⁸ (1996)	Rajput, Sirmour, Himachal Pradesh.	6.85	6.81	No
7	Kaur ⁷⁰ (1998)	Sikh, Delhi	6.80	6.73	No
8	Jain ⁷¹ (1999)	Jains, Delhi	6.70	6.66	No
10	Dr Vinay and Dr Manjulabai K.H. (2011, Present Study)	South Indians	6.64	6.80	No

$\sum S$ =Summation of Stature, $\sum T$ =Summation of Ulna Length

BILATERAL SYMMETRY

In the current study it was observed that there was no statistically significant difference ($p>0.05$) between the measurements of long bones of right and the left side in both the males and the females (Table no. 2). These findings are similar to that of Yayim yili³⁷, who has quoted that the difference between the length of bones of left and right side to be negligible. Our findings are also similar to that of Agnihotri, Kachhwaha, Jowaheer and Pratap Singh⁵², who observed that there was no statistically significant difference in the length of right and left tibia in both males and females. However, our observation is in contradiction to observation made by Mukta Rani Tyagi A.K, Verma S.K, Kohli A⁵¹ who concluded that left tibia is longer than right tibia in both sexes. Our observations are also in contradiction with the observation made by Schutlz⁵⁸, Dupertis C, Wesley and Hadden John A³⁶ who reported that bones of upper extremity are more asymmetrical, whereas greater similarity observed in bones of lower extremity. They also reported that the right side bones are longer than the left side. Similarly, Trotter and Gleser³¹ expressed that bones of upper extremity are longer on right side and all bones of lower extremity are longer on left side.

COMPARISON BETWEEN MALES AND FEMALES

In our study, with respect to bones of lower limbs there was no significant difference in the lengths of right and left tibia in males (p-value >0.05) as well as in females (p-value > 0.05). There is no significant difference in the lengths of right and left fibula in males (p-value > 0.05) as well as in females (p-value > 0.05). Similarly, there was no significant difference in the lengths of right and left radius in males (p-value > 0.05) as well as females (p-value > 0.05) and no significant differences were observed in the lengths of right and left sides of ulna in males (p-value > 0.05) as well as in females (p-value > 0.05) (Table no.2). However no other studies are available on this type of comparative analysis.

The applicability of the derived regression equations and multiplication factors are valid because, the difference between actual stature and calculated stature is insignificant ($< 1\text{cm}$, $p>0.05$) in both males and females, by using the derived regression equations and the multiplication factors (Table No. 9 and 10). However, no other studies are available to show this type of comparative analysis.

There is a positive correlation between the long bones of the forearm and leg with that of stature. Bilateral symmetry is present in the length of long bones of leg and forearm in each sex. Race and gender specific regression equation and multiplication factor are needed for the accurate stature reconstruction. We have come out with new set of regression equations and multiplication factors, gender wise. The regression equations and multiplication factors of present study can be used upon the south Indian population with fair degree of accuracy.

S e x	Bone (Right side)	Regression equations	Multiplication factors
F e m a l e	Tibia	Stature = $89.73 + (2.063 \times \text{Tibia length in cm.})$	4.39
	Fibula	Stature = $100.416 + (1.811 \times \text{Fibula length in cm.})$	4.38
	Radius	Stature = $105.15 + (2.546 \times \text{Radius length in cm.})$	6.84
	Ulna	Stature = $128.1 + (1.588 \times \text{Ulna length in cm.})$	6.35
M a l e	Tibia	Stature = $106.494 + (1.467 \times \text{Tibia length in cm.})$	4.33
	Fibula	Stature = $116.702 + (1.182 \times \text{Fibula length in cm.})$	4.36
	Radius	Stature = $121.185 + (1.661 \times \text{Radius length in cm.})$	6.59
	Ulna	Stature = $99.168 + (2.416 \times \text{Ulna length in cm.})$	6.29

- The project “Estimation of stature using percutaneous measurements of long bones of leg and forearm in south Indian population” was carried out at Jawaharlal Nehru medical college, KLE University Belgaum, Karnataka.
- The present study included 300 students hailing from south India (150 male and 150 females). Students of 20 to 30 years age group were selected for this study.
- There is bilateral symmetry in the length of long bones of leg and forearm in both the sexes.
- Regression formulae and Multiplication factors were derived for both sexes for right and left sides from percutaneous length of long bones of leg and forearm.
- The derived regression formulae differ in both sexes.

S e x	Bone (Right side)	Regression equations	Multiplication factors
F e m a l e	Tibia	Stature = 89.73 + (2.063xTibia length in cm.)	4.39
	Fibula	Stature =100.416 + (1.811xFibula length in cm.)	4.38
	Radius	Stature = 105.15 + (2.546xRadius length in cm.)	6.84
	Ulna	Stature = 128.1 + (1.588xUlna length in cm.)	6.35
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	Radius	Stature =121.185 + (1.661xRadius length in cm.)	6.59
	Ulna	Stature =99.168 + (2.416xUlna length in cm.)	6.29

- In both sexes stature estimated by derived regression formulae for length of respective long bones was similar to average actual stature with an error of less than 1cm which was statistically insignificant ($p > 0.05$).
- In both sexes stature estimated by derived multiplication factor for length of respective long bones was similar to average actual stature with an error of less than 1cm. This was statistically insignificant ($p > 0.05$).

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