PREDICTION OF THE FEMORAL LENGTH FROM MARKERS ON ITS PROXIMAL AND DISTAL ENDS

BY

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DECLARATION

I declare that the dissertation hereby submitted by me for the Master of Medical Sciences degree in the Faculty of Health Sciences at the University of the Free State is my own independent work and has not previously been submitted by me at another university/faculty. I furthermore cede copyright of the dissertation in favor of the University of the Free State.

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ABSTRACT

An estimation of stature from the whole length of limb bones is well documented. However, skeletal remains available for forensic work are often fragmentary. This study presents a prediction of the femoral length using markers on its proximal and distal ends. A total of 400 South African White and Black adult dried femora, devoid of gross pathology, and grouped by sex were obtained from the Raymond Dart Collection of Human Skeletons in the Department of Anatomical Sciences at the University of Witwatersrand, Johannesburg. The Maximum Femoral Length (FL), Neck-Shaft Angle (NSA), Neck Length (NL), Maximum Vertical Diameter of the Head of Femur (VDH), Intertrochanteric Apical Axis Length (ITAAL), Upper Breadth of the Femur (VHA), and Lateral Condyle Height (LCH) were measured. The data were statistically analysed using the various components of a PC version of SAS soft ware program. The student's t-test was used to calculate the significant differences of means between the sexes and races within the study sample as well as with other studies. The critical value for statistical significance was placed at the 0.05 level.

Correlation coefficients between femoral length and the other variables were calculated. The length of femur significantly and positively correlated with all segment measurements in both races and sexes. Femoral length was regressed on segment measurements individually and in combination and simple as well as multiple linear regression equations were developed for White and Black South Africans. Stepwise selection procedure was employed to formulate the multilinear regression equations. Most of the models developed in the present study are significant at $p< 0.0001$, r^2 values are high, and standard errors of the estimates (S.E.E.) are very low. Therefore, the equations developed in this study present a reasonable degree of accuracy for the estimation of femoral length from its proximal and distal segments in South African Whites and Blacks.

Once the length of femur is established, it is possible to calculate living stature of the individual with a reasonable degree of precision. The necessity of population and sex specific regression models is addressed.

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CHAPTER 1: INTRODUCTION

Among the determinations that forensic anthropologists try to arrive at in examining skeletal remains are sex, age, race, stature, weight and handedness – that can be called general traits (Stewart, 1979). Anatomists are frequently called upon to give an expert opinion on the status of a deceased from the bones recovered in forensic work (Kate and Mujumdar, 1976). Human bones are of considerable importance as they unveil significant information regarding their origin. Anthropometric analysis of long bones provides information regarding sex, age, race, and stature of an individual. The estimation of stature from length of long bones of the limbs is often an important contribution to the identification of unknown human remains (Trotter and Gleser, 1952). This information is of considerable interest to the anatomist, anthropologist, forensic pathologist, and forensic scientist. Stature is of forensic and anthropological significance (Prasad *et al.*, 1996).

The estimation of human stature from various skeletal elements has been an area of critical interest to physical anthropologists (Krogman, 1962). In physical anthropology, stature estimation from long bones by mathematical methods has a long history and is based on the same logical, general principle – a linear relation exists between bone length and body height (Krogman, 1979). Past studies concerning stature estimation have included groups that are racially and geographically diverse (Simmons *et al.*, 1990). The studies presented data and statistical formulae for the determination of stature based on various long bone lengths. All of these studies have demonstrated that there is a high correlation between the length of any whole, long limb and stature (Telkka, 1950; Trotter and Gleser, 1952; Keen, 1953; Allbrook, 1961; Kate and Mujumdar, 1976; Olivier *et al.*, 1978; Lundy, 1983; Vettivel *et al.*, 1995; Prasad *et al.*, 1996). Trotter and Gleser (1952) documented that in every set of equations, stature has a smaller standard error of estimate when computed from bones of the lower limb than when computed from bones of the upper limb. Thus, the femur, the tibia or the fibula give the best estimates of stature for each group. According to their study, a comparison of estimates between femur and humerus indicates that the range of errors in every case is smaller for the femur. Finally, they argue that equation utilizing the sum of the lengths of femur and tibia gives a result in every group of nearly, if not the maximum, validity. In no estimation of stature should the humerus and radius be used separately or in conjunction with each other if the other bones are available, since the bones of the upper limb result in greater errors of estimate than bones of the lower limb. Similarly, Simmons *et al.* (1990) reported that the femur usually has the highest single correlation with stature.

A drawback to mathematical techniques of estimating stature has always been limited applicability to fragmentary remains. With a few exceptions, most of these techniques require substantial portions of the skeleton , or at least one intact limb bone, to accurately estimate height. Yet archaeological specimens commonly are recovered with no intact or even reparable, long bones. The same is true in many forensic-science cases (Holland, 1992). Steele and McKern (1969), and Steele (1970) attempted to overcome this handicap by devising a technique that uses measurements of long-bone segments rather than intact elements. Unfortunately the effectiveness of this method in less-skilled hands is limited, since it may be "difficult to locate the necessary anatomical landmarks" required (Bass, 1987). Simmons *et al.*, (1990) presented a "revision of the Steele method" that is applicable to fragmentary femora using well-defined, easy to locate anatomical land marks and standard measurements. By employing well-defined markers, Simmons *et al.* (1990) concluded that the three variables showing the highest and most consistent correlations with maximum femur length and stature are upper breadth of the femur, maximum vertical diameter of the femur head, and lateral condyle height. Similarly Prasad *et al.* (1996) studied 171 adult dry femora in India. Using well-defined markers, they showed that neck-shaft angle, neck length, intertrochanteric apical axis length and vertical diameter of the head of femur correlated significantly with femoral length. The authors derived a simple linear regression equation to calculate the femoral length using any one of these markers.

If the body has been dismembered or if the skeleton is disintegrated, the stature may be calculated by applying regression equations to lengths of whole or fragments of long bones. Similarly, length of long bone may be calculated by applying regression equations to its fragments (Simmons *et al.*, 1990; Prasad *et al.*, 1996). Once th length of a long bone is determined, it will be possible to estimate stature of the unknown using available regression equations, tables, and multiplication factors

1.1 LITERATURE REVIEW

1.1.1 STATURE ESTIMATION FROM THE WHOLE LENGTHS OF THE SIX LONG BONES OF THE LIMBS (FEMUR, TIBIA, FIBULA, HUMERUS RADIUS, AND ULNA)

The determination of human stature and other demographic characteristics from intact long bones is often an important contribution to the identification of unknown human remains. Numerous studies have been carried out over a long period of time and involving diverse population groups in an attempt to develop standards for the determination of age, sex, stature, race, etc. from intact long bones. The biometrical relationship between the length of the various long bones and the stature of the individual has been extensively quoted and used by medico-legal authorities, and almost all textbooks give instruction in calculating stature from isolated bones (Keen, 1953). Interest in stature estimation from whole long bones is not new and several reports have been documented by various authors in this regard. No other identification procedure used by forensic anthropologists has undergone such a complicated course of development involving so many identifiable contributors as that concerned with the estimation of stature from more or less detached parts of the skeleton.

Jean Joseph Sue (1755) published four body measurements and the maximum length of many of the bones of fourteen cadavers ranging in age from a six-week-old fetus to an adult of twenty-five years. The body measurements – stature, trunk length, upper-extremity length, and lower-extremity length – provided perhaps the first clear documentation of two important facts concerning changes in body proportions during growth, namely 1) that the length of the trunk exceeds that of the lower extremities until about fourteen years of age, after which both lengths are equal (in other words, after fourteen the pubic symphysis is usually the center of body length); and 2) that the length of the upper extremities exceeds that of the lower extremities until about birth, after which the lower extremities are longer. Sue said little about how the measurements were taken, but clearly indicated that the units of measurement were the pied (foot), pouce (thumb or inch), and ligne (line, 12 to the inch). His purpose in publishing the measurements was to provide artists with a means of rendering the human body in correct proportions.

Matthieu Joseph Bonaventure Orfila (1821-23, 1831) brought Sue's measurements to wider attention in two medico-legal textbooks. Also, in these books he followed Sue's example and reported the same selection of measurements for his own series of 51 cadavers and 20 skeletons. He departed from Sue's example only in using the metric units of measure. In order to determine the stature of a skeleton from the measurements of Sue and Orfila one needed to measure the length of one or more bones, say a femur and/or humerus, then find in the tables comparable bone lengths and note the corresponding cadaver statures. Not until some years later did anyone question the equivalence of cadaver stature and living stature (Stewart, 1979).

Paul Broca (1824-1880), a medical anthropologist among many other things, introduced the osteometric board for measuring long bone length more accurately. Broca (1862) and Hamy (1872) worked on the proportion of the humerus to body length.

In Britain early in the nineteenth century, much effort was being expended on determining the statures of the ancient races of that country. Consequently the British anthropologists appear to have taken as much interest in the Sue-Orfila measurements as did the British medico-legal experts. John Beddoe (1826-1911) in particular combined the Sue-Orfila measurements with their own to investigate the relationship of long bone lengths to stature. While differing from the French methods of stature estimation, the British methods had in common an adjustment of femur length and the multiplication of this length by a given number. Beddoe's description of his own method (1888) provides a good example: "I take away from the length of the femur one-quarter of the excess over 13 inches up to 19, and thereafter only one-eighth; and then multiply by four."

Paul Topinard (1885a, b, c; 1888) published papers discrediting the procedures used in Britain, giving a method of his own, and appealing for skeletal data collected according to recommendations he set forth. By combining his own data with those of Orfila, Topinard (1888) had measurements on a series of 141 skeletons with which he showed that for the combined sexes the following average long bone/stature (= 100) ratios held:

MAXIMUM LENGTH OF HUMERUS	MAXIMUM LENGTH OF RADIUS	MAXIMUM LENGTH OF FEMUR	MAXIMUM LENGTH OF TIBIA
20.0	14.3	27.3	22.1

Using these ratios, he offered the following formula for stature estimation:

R:100::L:x; where R = the relationship of the particular long bone length to stature (= 100),

L = the length of the bone measured, and x = the stature sought. The latter is the stature of the skeleton. Thirty-five mm should be added in order to get the true stature, that of the living.

The most significant report in the nineteenth century was that by Rollet in 1889. He measured stature and lengths of the long- bones of 50 male and 50 female French cadavers ranging in age from 24 to 99 years and presented all pertinent data including not only the methods of measurement but also the individual measurements and the resultant tables for stature estimation. Stature measurements were taken "generally in the week which followed death" with the cadaver lying on a graduated stretcher. The soft parts were then dissected away from the long bones which were measured on the osteometric board of Broca in the "fresh state" without having gone through maceration. A "certain number of the bones" were measured 8 or 10 months later in the "dry state" and it was determined that they had lost in general 2 mm of their length. Thus, when stature is to be estimated from the length of "dry" bones it has been the practice to add 2 mm to the measured length of each bone before application of Rollet's tables. The greatest length of the humerus, radius, ulna and fibula; both greatest and bicondylar lengths of the femur; and the distance from the two condyles of the head (with the intercondyloid eminence in the opening of the board) to the extremity of the medial malleolus of the tibia were taken. The tables present the average length of each of the 6 long limb bones of each side of the body for a given range of stature.

Almost immediately Léonce Manouvrier (1893), having taken exception to the way in which Rollet had developed and organized his tables, published his own version which thereafter, owing to Manouvrier's prestige, alone was widely used. The raw data of Rollet served as a basis for application of different methods by Manouvrier. Manouvrier excluded those subjects of 60 years of age and over, 26 males and 25 females. He stated that due to the effect of "old age" on the length of the trunk they had lost 3 cm of their maximum stature. From data on the remaining 49 subjects (24 males and 25 females) he derived tables of average stature corresponding to average long bone lengths. In other words, Manouvrier determined the average stature of those individuals who presented the same lengths for a given long bone, whereas Rollet determined the average length of a given long bone from those who presented the same stature. The values obtained by these two methods are not interchangeable. Manouvrier also took into account the fact that Rollet had measured the bones while fresh. He included with his tables therefore the recommendation that in using them to determine stature from dried bones, 2 mm be added to the dried bone length for cartilage loss and that 2 cm be added to the corresponding statures in the tables to convert cadaver stature to living stature.

Manouvrier's tables in turn were superseded, although not as quickly, by a new statistical procedure of the biometric school in England. Karl Pearson (1899) applied stature regression formulae utilizing all of Rollet's cases, but limiting long bone lengths to those of the right side unless the right bone was missing in which cases he used the left. He was aware of the wide age range but included all in calculating the constants noting that 50 cases are hardly sufficient for this method of treating data. He also reasoned that since there were as many old individuals with a stature above as below the median stature, "whatever shrinkage may be due to old age if it is not of a very marked character in these data or largely disappears when a body is measured after death on a flat table." The mean stature of the 26 males over 59 years of age was only 1.77 cm less than the mean stature of the 24 males under 60 years of age; the older group of females presented a mean stature of only 0.04 cm less than the younger group. Trotter and Gleser (1951a) noted that Pearson failed to take cognizance of the greater long bone length in the older group of females than in the younger group and that the older group, therefore, had been taller individuals in their younger years than the stature measurements after death indicated. Pearson made a most valuable contribution to the problem of reconstruction of stature but emphasized that his formulae and curves must not be taken as final, that they merely represent the most probable conclusions which could be drawn from the data at his disposal. He hoped for a wider range of facts, more refined analysis, experiment and observation. In the course of his discussion he stated that "the extension of the stature regression formulae from one local race – say, modern French – to other races – say, palaeolithic man – must be made with very great caution" and "stature is quite as marked a racial character as cephalic index." Commenting on Pearson's work, Stewart (1979) said that Pearson not only changed completely the prevailing approach to stature estimation, giving us a more truly "mathematical method," but he departed in other ways from previous practices. Whereas Topinard, like his predecessors, had preferred maximum femur length (Rollet took both maximum and oblique femur lengths) and Manouvrier had preferred oblique length, Pearson went back to maximum length. And whereas both Topinard and Manouvrier had objected to the inclusion in the cadaver series of individuals over sixty years of age, Pearson saw no reason to omit any of Rollet's aged subjects. Moreover, since Pearson's main reason for entertaining this field was to continue the traditional British investigation of the statures of ancient races, he produced separate series of regression equations for both fresh and dried bones. In the latter pursuit he had to estimate what Rollet's bone lengths would have been if taken after the bones had dried. This led him to deduct from Rollet's fresh-bone lengths 1) the thickness of the joint cartilages given in Heinrich Werner's Inaugural Dissertation (1897), and 2) the amount of lengthening found to occur in ancient long bones when immersed in water for 120 hours.

Stevenson (1929) was the first to test the general applicability of Pearson's equations. He accumulated data on a contemporary group of 48 Northern Chinese male cadavers (no ages given) according to methods which were the same as those applied by Rollet. He calculated stature regression formulae of each race to the other. The result was a failure of the formulae of one race to give satisfactory prediction results for the second. He emphasized the need of additional data in the form of similar series of regression formulae based on comparable data from other races. Pearson stated frankly that he was prepared to admit that better results from regression formulae would be obtained by applying a formula specific to a race itself than by applying a formula arising from a second race.

Breitinger (1937) approached the problem with the statistical methods introduced by Pearson but his data were from living subjects. He pointed out that cadaver material is ill-suited since it mostly represents a certain selection of the population according to age, socio-economic status and geographical distribution; and that stature measurements of cadavers are encumbered with greater errors than stature measurements of the living. His subjects comprised 2400 German males of which 1400 were participants in an athletic meeting in Munich in 1923 and 1000 were students in 1925-26. The average age was reported to be about 26 years. Measurements of pertinent diversions of the limbs were taken between certain bony prominences and thus were not as accurate as measurements derived directly from the bones themselves as cited by Trotter and Gleser (1952).

Leaving aside Breitinger's (1937) contribution to his field because of its very different methodological approach, Manouvrier's tables and Pearson's equations were regarded throughout the early decades of the twentieth century as the only acceptable means of stature estimation. Also, each had its advocates. In the United States, Hrdlicka (1920, 1939) included Manouvrier's tables, but not Pearson's equations in his Anthropometry. On the other hand, Martin's *Lehrbuch der Anthropologie* (1928), offered both the tables and the equations; where as Krogman (1939) offered in his Guide only the equations (Stewart, 1979).

Telkkä (1950) presented a chronological review of the literature in addition to his own results based on 154 Finnish cadavers, 115 males and 39 females. The average age of the males was 42.3 years and the females 50.4 years. The stature was measured on the 'prostrate' corpse and the bones were measured after maceration and drying. The skeletons had not all been preserved intact and thus the number of bones of a kind available for measurements was somewhat smaller than the number of subjects. The statistical treatment comprised correlation and regression coefficients between stature and bone measurements.

At the symposium on applied physical anthropology, Stewart (1948) commented on the deficiencies of the Rollet data upon which both Manouvrier's tables and Pearson's equations are based, and he said "Someone should work up the extensive records of cadaver stature and bone lengths assembled at Western Reserve University and Washington University [St. Louis]. We need not only better correlation data for Whites, but special data for other races and a better idea of the probable error involved in individual determinations." Depertuis and Hadden (1951) as well as Trotter and Gleser (1952) responded accordingly.

Depertuis and Hadden (1951) at Western Reseve University have responded by their analysis of groups of 100 male and 100 female American Whites and an equal number of both sexes of Blacks from the Todd Osteological Collection. In stature measurements, the subjects were secured in the upright position by means which insured that the heels were fairly planted on the floor. Comparing their mean cadaveric statures with means derived from several large series of living Americans, they concluded that their cadaver length was equivalent to living stature. Their calculations of the regression formulae were based on the values of the bones of the right side only.

Mildred Trotter and Goldine C. Gleser at the Washington University, St. Louis, made an outstanding contribution to the subject of stature estimation in December 1952. Their report included a study of evidence available in the Terry Anatomical Collection as well as data from the military personnel. For the first time they were able to compare long bone lengths with the known living stature of American military subjects. The military personnel were drawn from American World War II casualties in the Pacific zone. Their remains had been skeletonized by natural processes during the temporary burials and the bones were clean and dry. Stature measurements had been recorded at the time of induction into military service in a reasonably similar way. The Terry Skeletal Collection is composed of complete skeletons of American White and Black cadavers which had been assigned to the medical school for scientific study. The collection is well documented with respect to race, sex and age. From the military personnel, they used principally 710 White males and 68 - 80 Black males. The subjects studied in the Terry Skeletal Collection were 255 White males, 360 Black males, 63 White females and 177 Black females with a total of 855 subjects.

The right and left long bones of both upper and lower limbs were considered, viz. humerus, radius, ulna, femur, tibia, and fibula. The statistical analysis consisted of regression equations based on a linear relationship between the variables. Even though this method had been used by previous workers who dealt with the subject before them, they introduced three refinements: one, the utilization of stature measured on the living in combination with bone lengths measured after death on the dry skeleton; two, recognition of and adjustment for the effect of ageing on stature; and three, a test of validity of the resultant equations by application to a different sample of reasonably large size.

According to their analysis, there was neither a large nor consistent difference in the amount of correlation for right and left bones of any pair except for the radius in which instance the left bone had a higher correlation with all other bones and with stature than did the right radius. Since the difference in standard deviation for any two corresponding bones was likewise very small there could be very little difference between estimation equations for stature evolved from them.

Regression equations for estimation of stature from the length of each long bone and from the lengths of multiple bones were determined for each group of subjects available from the two sources. The single bone equations were almost identical for the two lengths of femur and for the two lengths of tibia, thus only the maximum length of each bone was utilized in the multiple bone equations. In both single and multiple equations the bones of the lower limb resulted in estimations of stature with a smaller standard error than did the bones of the upper limb.

They also presented equations for estimation of long bone lengths (humerus, radius, ulna, tibia, fibula) from the femur for Whites and Blacks of both sexes.

The increase in cadaver stature over that of living stature was estimated to be 2.5 cm. When this correction was made and loss of stature from ageing was taken into account, the equations for estimation of stature of males based on data from the Terry Collection and from the military personnel were shown to be in substantial agreement. It was then reasonable to assume that equations based on females of the Terry Collection, with corresponding adjustments were likewise applicable to the American population of White and Black females. Their equations are applicable to maximum lengths of long bones which are dry and without cartilage. According to Trotter and Gleser (1952), the resultant estimates were of maximum living stature and could be reduced by the amount of 0.06 (age in years – 30) cm to cover the effects of ageing. A test of the equations for White males by application to a different sample of American White Military personnel gave results well within the expected range of accuracy. Comparison of statures for the new sample according to equations (involving femur and humerus) developed in the study of Trotter and Gleser (1952) with those of other investigators demonstrated that their formulae gave the most accurate estimates of stature. Another comparison involving the application of each investigator's equation (based on the femur) to every other sample of like sex demonstrated the advantage of the age factor in the equation and also the need for an adjustment when cadaver stature is utilized as a measurement of living stature.

Finally, Trotter and Gleser (1952) concluded that the Blacks of both sexes had significantly longer bones of the limbs than do the White groups; the Blacks also had longer forearm and leg bones relative to the arm and thigh bones than did the Whites; and, in general the Blacks had longer bones of the limbs relative to their stature.

Genoves (1967) collected data to devise appropriate formulae for calculating stature among Mesoamericans from measurements of their long bones. Cadavers used for the study were those obtained by the National School of medicine from hospitals in the Federal District of Mexico for educational purposes. A total of 235 (176 males and 59 females) cadavers were measured. Of these blood samples of 132 (103 males and 29 females) were drawn. Only those cadavers of which the long bones could be measured afterwards were used in the investigation, and of these only those whose blood was of group O and Rh+. A sample of 98 (69 ales and 29 females) was thus arrived at and divided morphologically into seven categories going from "pure" Indian to "pure" white. The maximum lengths of the femur, the tibia (without the tuberosity), the fibula, the humerus, the ulna and the radius were measured. Bones from both sides were measured without being distinguished, since the differences were not significant. Means and standard deviations were calculated for all six unpaired long bones and for stature, as well as the coefficient of multiple correlation among the seven variables, for both males and females.

Mean stature for this population was 161.50 cm and 149.80 cm for males and females, respectively after 2.5 cm was deducted from cadaver measurements. As the sample was morphologically and serologically as close as one could get to pre-hispanic conditions and as the statures arrived at were representative of what was known, tables were drawn giving the corresponding values of statures of males and females going from 180 cm to 130 cm at steps of 0.5 cm. The author concluded that the newly drawn tables and formulae were more appropriate to calculate stature from long bones of American pre-hispanic populations than any other used before.

In India, Pearson's formula was the most commonly used method to determine the height. These regression equations were subjected to verification by Kate and Mujumdar (1976) on 194 (97 pairs) femora and 102 (51 pairs) humeri from India. It was seen that Pearsonian formulae did not give exact results. The regression formulae differed statistically in both sexes in femur and humerus. This finding once again proved the necessity of having norms or formulae for the specific groups, when reliable results are required. In addition, the proportion between humerus length and femur length was also verified. This has evolutionary significance. In addition to the usual method, a method of the proportion these bones individually bear to the stature of the same person to which the bones belong was worked out both as a multiplication factor and percentage proportion to the body stature. It had been amply demonstrated and concluded that this method be called "autometry" and further that "this seems to be a more reliable method than the tedious yet variable and unreliable results the various formulae give." According to them this autometry seems to have consistency, being constant in both sexes and all races, thus evolving a 'human race autometry'.

In 1978, Olivier *et al.* presented an article aimed at improving and completing the classical formulae for estimating stature which we owe to Manouvrier (1893, 1898), Lee and Pearson (1901) and Trotter and Gleser (1958). It was a result of a series of studies published before in French; however, it was more than a mere condensation, since the number of subjects had been modified, usually increased, and the statistical method improved: instead of using simple regressions, the most probable values were indicated using multiple regressions. This was important since a certain lack of precision, which characterizes these estimations, is attenuated by the multiple regressions.

Sciulli and Giesen (1993) presented regression equations to estimate skeletal height and stature for prehistoric Native Americans of Ohio. The regression equations are based on skeletal height as the dependent variable and various postcranial elements and combinations of elements as the independent variables. A total of 171 individuals, 95 males and 76 females, made up the sample. The sample included the 64 individuals who were previously used for stature estimation (Sciulli *et al.*, 1990) and 107 additional individuals distributed more widely in time and space. This more inclusive sample, however, showed the same proportional contributions to skeletal height of each skeletal height component as the previous sample. The result suggested that the proportions were a consistent feature of the prehistoric Native Americans of Ohio. In conclusion, they stated that since the prehistoric Native Americans of Ohio were characterized by relatively long legs and distal elements of the limbs, stature estimation from regressions based on East Asian populations, which expressed in general relatively short legs and distal limb elements, would overestimate stature in Native Americans of Ohio and, possibly, all Eastern Woodlands Native Americans.

The correlation between the postmortem stature and the dried limb-bone lengths of Korean adult males was examined by Choi *et al.* (1997). The postmortem stature was measured in 57 Korean adult males (age range: 20-86 years old, mean: 52.3 years old) in supine position. After dissection of the corpses, they measured the maximum length of the remaining limb-bones (humerus, radius, ulna, femur, tibia and fibula). The correlation coefficients between the stature and each limb-bone length were calculated. Simple regression equations for estimation of stature from each limb-bone length and multiple regression equations from the combination of limb-bone lengths were obtained.

Research was undertaken by De Mendonca (2000) on 200 individuals (100 males and 100 females) from the northern districts of Portugal, all Caucasians, between the ages of 20 and 59. Height and bones were measured directly. Estimation of stature was obtained by applying a mathematical method based on a multivariable linear regression between the height of the cadaver and the lengths of humerus and femur. Humerus was measured in full length; femur was measured on both physiological and maximum lengths. Regression formulae and tables for males and females were produced for application in forensic anthropology when studying human skeletal remains. Comparisons were made between these tables and those of earlier authors to verify important differences. One of the conclusions concerns the application of regression formulae based on some segment measurements. According to the author, however, these might have no practical application due to the extreme high values of standard deviations.

Ross and Konigsberg (2002) presented local standards for stature prediction formulae using a Bayesian approach to aid in identifications of the victims of genocide in the Balkans. The Eastern European sample was 177 males and included both Bosnian (N = 86) and Croatian (N = 91) victims of war. The reference sample was 545 American White males obtained from World War II data. Because the actual statures for the Balkan War dead were not known, the mean and standard deviation for 19-year old males was taken from the literature (Tomazo-Ravnik, 1988). Results showed that formulae based on Trotter and Gleser systematically underestimated stature in the Balkans. For the humerus, the Trotter and Gleser formulae underestimated stature on the lower bounds of the confidence interval, while on the upper limits it overestimated stature because of a larger standard error in the Trotter and Gleser prediction equation. Estimates for the tibia, per contra, the Trotter and Gleser formulae overestimated stature on the upper bounds of shorter long bones, while underestimating stature on the lower bounds, and overestimated stature of longer long bones. This could also coincide with differences in standard errors between the prediction equations and possible proportional differences between the populations. Ross and Koningsberg (2002) then presented new predictive stature univariate regression equations for Eastern European males. In conclusion, the authors recommended that because eastern Europeans are taller than American Whites, it is appropriate to use their work as an ‘informative prior’ that can be applied for future cases. This informative prior can then be used in the predictive formulae, since it is assumed to be similar to the sample from which Balkan forensic cases were drawn.

Radoinova *et al.* (2002) carried out stature estimation from long bone lengths in Bulgarians. The purpose of their study was to develop a new regression procedure for predicting stature from the length of long limb bones taking into account sex – and age-related changes. Statures and lengths of humerus, tibia and fibula were measured in 416 forensic cases (286 males and 130 female adult Bulgarians). Measurements of the bones and the statures were made on cadavers before autopsy. Stature regression analysis was performed for each of the three bones, as well as for a combination of humerus and tibia. Resulting models were tested for outliers and heteroscedasticity. Anova test for model adequacy and covariance matrix of regression parameters were calculated. 95% confidence intervals of the error term were determined. Nomograms for a direct application of the results were constructed where it was convenient. In conclusion, the authors stated that the method provides easy and more reliable results of stature estimation for the Bulgarian population than other formulae.

1.1.2 STATURE ASSESSMENT USING OTHER BONES, SOMATOMETRY AND OTHER TECHNIQUES

Various researches have been done in an attempt to estimate from other bones, using somatometry and other techniques. Although best results are achieved using long limb bones, a variety of bones may be used for the estimation of stature (Trotter and Gleser, 1952; Choi *et al.*, 1997; Muňoz at al., 2001).

Estimation of stature from the dimensions of foot or shoe has considerable forensic value in developing descriptions of suspects from evidence at the crime scene and in corroboration with the height estimates from witnesses. Gordon and Buikstra (1992) extended the findings of previous researchers by exploring linear models with and without sex and race indicators, and by valid use of the most promising models on large collection of military database. Boot size and outsole dimensions were examined as predictors of stature. The results of the study indicated that models containing both foot length and foot breadth were significantly better than those containing only length. Models with race / sex indicators also performed significantly better than do models without race/sex indicators. However, the difference in performance was slight and the availability of reliable sex and race information in most forensic situations is uncertain. Analogous results were obtained for models utilizing boot size / width and outsole length / width, and in the study these variables performed nearly as well as the foot dimensions themselves. Although adjusted R^2 values for these models clearly reflected a strong relationship between foot/boot length and stature, individual 95% prediction limits for even the best models were +/- 86 mm (3.4 in). This suggested that models estimating stature from foot/shoe-prints may be useful in the development of sub descriptions early in a case but, because of their imprecision they may not always be helpful in excluding individual suspects from consideration.

Bhatnagar *et al.* (1984) presented identification of personal height from the somatometry of the hand. The study was based on a sample of 100 normal Punjabi males from patiala, Punjab, India. Each subject had been studied for three anthropometric measurements: Stature, hand length and hand breadth. The data had been subjected to statistical computation for the statistical constant like p values, standard deviation, standard error of mean, test of significance (test of normal deviates) and regressions. The data had been studied for somatometry pertaining to height, hand length and hand breadth. Bilateral symmetry in both measurements, hand length and hand breadth indicated insignificant variations. The authors computed regression equations and presented regressions lines for the estimation of stature from somatometry of hand.

Saxena (1984) attempted to find out possible correlations among hand length, hand breadth (stretched) and sole length and derive a regression formula to estimate stature from them. The study was based on the measurement of 100 Nigerian male medical students of the Jos Medical School, Nigeria, between the ages of 20 – 30 years. The results showed that there are significant correlations between the stature of an individual and hand length, hand breadth and sole length.

Muncie *et al.* (1987) presented a practical method for estimating stature of bedridden female nursing home patients. An accurate stature obtained by summing five segmental measurements was compared to the stature recorded in the patient's chart and calculated estimates of stature from measurement of long bone (humerus, tibia, knee height). Estimation of stature from measurement of knee height was highly correlated ($r = 0.93$) to the segmental measurement of stature while estimates from other long-bone measurements were less highly correlated ($r = 0.71$ to 0.81). Recorded chart stature was poorly correlated ($r = 0.37$). Based on the results of their study, measurement of knee height provided a simple, quick, and accurate means of estimation of stature for bedridden females in nursing homes.

Byers *et al.* (1989) presented the results of a study to determine the value of foot bone in reconstructing stature. The data consisted of length measurements taken on all ten metatarsals as well as on cadaver length from a sample of 130 adults of documented race, sex, stature, and, in most cases, age. Significant correlation coefficients (0.58 – 0.89) were shown between known stature and foot bone lengths. Simple and multiple regression equations were computed from the length of each of these bones. The errors were larger than those for stature calculated from complete long bones, but were approximately the same magnitude for stature calculated from metacarpals and fragmentary long bones. Given that metatarsals are more likely to be preserved unbroken than are long bones and the ease which they are accurately measured, the authors believed that their formulae should prove useful in the study of historic and even prehistoric populations.

Shintaku and Furuya (1990) made regression formulae to estimate stature of Japanese females by the proximal phalangeal length of the hands of 231 Japanese female students. The stature and the proximal phalangeal length produced correlation coefficients ranging from 0.521 to 0.696, and the resulting regression formulae possessed standard errors ranging from 3.59 to 4.27 cm. Their results showed that the proximal phalangeal length could be used as a reliable estimator of stature.

Tarazawa *et al* (1990) made studies on Japanese males (n = 42) and females (n = 29) autopsied during 1984 – 1987 in order to estimate stature from the length of the lumbar part of spine (LLPS). Somatometry was made on the stature and LLPS in centimeters, the latter being measured from the edge of the first lumbar vertebral body, to the promonitory along the anterior surface of the spine. LLPS were 19.9 +/- 1.19 cm in males and 18.6+/-0.84 cm in females (mean +/-S.D.). The regression equations calculated were as follows: stature in males = LLPS x 3.23 + 101.7; stature in females = LLPS x 2.31 + 110.8. The standard errors of estimate were 6.16 cm in males and 4.05 cm in females. They recommended that this method is useful for estimating the stature of severely burned or mutilated bodies which have no limbs.

Estimation of stature from foot and shoe measurements using multiplication factors is well known. It is a simple method and used very frequently as a ready reckoner in forensic anthropology. However, the individual error is quite large. Jasuja *et al.* (1991) attempted to evolve revised multiplication factors to reduce this error so that this method (multiplication factor) could be used more effectively with smaller error.

Meadows and Jantz (1992) presented formulae for the estimation of stature from metacarpal lengths. Two samples of metacarpal specimens were employed in the analysis: One of 212 individuals from the Terry Collection, and one of 55 modern males, all of whom had measured statures. One measurement, the midline length, was taken on each metacarpal. Stature was regressed on the basis of the metacarpal length to derive equations for the Terry Collection individuals. Comparisons between the Terry Collection males and the modern sample showed the latter to have longer metacarpals and greater statures. The Terry equations were tested using the modern male sample. In spite of the differences noted, the Terry equations performed acceptably on modern individuals. The performance was slightly better for whites than for blacks. The authors warned researchers that since the female equations were not tested, they should be employed with greater caution.

Kimura (1992) examined a relationship between stature and second metacarpal length by means of a linear regression for sex, skeletal age and locality in 2056 children aged 6-19 years in five districts of Japan. Significant differences (P less than 0.05) were found for the regression of two measurements between immature and mature groups according to the TW2 method. Few significant differences were found in the regression with sex and locality in both immature and mature groups. Stature could be estimated from the second metacarpal length with standard errors of 44mm in the immature group and 40mm in the mature group. Furthermore, from the bone length and age, stature could be estimated with a standard error of 3cm for each sex in combined groups. These figures were similar to the variability in stature at a given age and comparable to the reliability of estimates from long bones. According to the author, the second metacarpal length may be a reliable and practical marker in children for the estimation of stature by means of a general formula regardless of sex and locality in a population.

Jasuja and Manjula (1993) presented a report on stature determination from foot and shoe stride lengths. They justified that the stride length of a person is related to the height of the person and the speed at which he is walking. In their work, they formulated certain constants and equations for stature determination from stride length.

Singh and Phookan (1993) attempted to examine relationships between stature and foot length, stature and foot breadth, foot length and breadth among four Thai (male) populations of Assam (India), viz. the Khamyangs, the Turungs, the Aitons, and the Khamitis. Significant positive correlations were found in all the cases. Mean values of the indices revealed a more or less constant ratio of stature and foot size at all heights suggesting the possibility of estimating stature from foot length or breadth or vice versa. Estimation of stature from foot length is, however, preferable to estimation from foot breadth. The Turungs stood for the tallest in stature and biggest foot measurements. They fell into 'medium' stature of the Martin's scale while the others fall into 'below medium'. Statistically significant difference was observed between the Turungs and the Khamyangs in respect of foot breadth and between the Turungs and the Aitons in foot length and, between the Khamyangs and the Khamitis in respect of stature-foot breadth index.

In order to estimate stature from the length of cervical, thoracic, lumbar, thoraco-lumbar (T-L) and cervico-thoraco-lumbar (C-T-L) segments of the spine, Jason and Taylor (1995) made measurements on white and black Americans, both male and female, autopsied during 1977-1993. Sample sizes were as follows: white males = 167; white females = 58; black males = 43; black females = 31. Separate measurements were made of the vertebral segments along the anterior surface of the spine. Regression formulae were calculated for each segment in each of the four groups. Standard errors of estimate ranged from 2.60 to 7.11 cm. Comparison was made with previous work published for Japanese. The Japanese formulae could not predict stature of the American populations using the data for the Americans. The authors recommended that the method is useful for estimating the stature of severely burned or mutilated bodies.

Holland (1995) presented a report on estimation of adult stature from the calcaneus and talus. Calcanei and tali of 100 skeletons in the Hamann-Todd collection at the Cleveland Museum of Natural History were measured. The skeletons represented 50 males and 50 females distributed equally by race, i.e., whites and blacks. Linear regression equations, with standard errors ranging from 4.09 to 6.11 cm, were derived from these measurements for the purpose of estimating stature. Two independent control samples, including one comprised of remains of American servicemen lost in World War II and the Korea and Vietnam Wars, were tested with relatively accurate results.

Han and Lean (1996) derived regression equations using lower leg length or arm span to predict height The subjects included determination sample of 78 men and 82 women aged 17-70 years, and validation sample of 53 males and 121 females aged 18-82 years. Height, weight, lower leg length measured from the top of the patella with the knee flexed to 90 degrees, arm span, % body fat by densitometry, and age were recorded for the sample. The results showed that lower leg length gave prediction of height (males: r^2 = 79%, SEE = 3.2 cm; females: r^2 = 73%, SEE = 3.4 cm). Applying the equations to a separate sample of male and females based on lower leg length and weight/lower leg length ratio showed 95% of the errors of height estimate were within 6.5 cm.

Ashizawa *et al.* (1997) measured stature, body weight, left foot length and breadth on East Javanese, Filipinos in Northern Luzon, Japanese in Tokyo. No footwear was used by the Javanese, rubber sandals were used by the Filipinos, and sneakers or leather shoes by the Japanese group. Regression lines regardless of age were obtained among these four measurements, body mass index (BMI), and relative foot breadth to foot length. The relationships between general size and foot size/shape were examined with regard to footwear. The results can be summarized as follows: (1) in either sex, compared with the Japanese, the East Javanese had a longer foot for the same stature and body weight, wider foot for the same BMI and the same foot length; (2) the relationship between BMI and foot shape (breadth/length) was nearly the same in the Filipinos and the Japanese females; (3) sexual dimorphism of the foot was greater among the East Javanese than among the Japanese; (4) as body size/weight increased sexual dimorphism diminished among the East Javanese, whereas it was more emphasized among the Japanese; (5) the appropriateness of the regression equations obtained from measurements of contemporary barefoot people for estimation of stature of prehistoric humans was supported.

Chiba and Terazawa (1998) carried out a study on Japanese cadavers (comprising 77 males and 47 females) in order to investigate the possibility of estimating stature from somatometry of the skull. Somatometry of the skull was performed on diameter (distance between glabella and external protuberance) and circumference (length around the skull through two points: the glabella and external protuberance). The regression equations calculated were as follows: stature in males = (diameter + circumference) x 1.35 + 70.6 (standard error of estimate (S.E.) = 6.96 cm); stature in females = circumference x 1.28 + 87.8 (S.E. = 6.59 cm); stature in both sexes = (diameter + circumference) x 1.95 + 25.2 (S.E. = 7.95 cm). The authors admitted that these S.E.'s appear to be larger than those obtained for other parts of the body. They, however, suggested that in cases where identification is required by means of only the skull, this method could prove useful.

Muñoz *et al.* (2001) presented formulae for stature estimation from radiographically determined long bone length in a Spanish population sample. They measured the stature of 104 healthy adults from Spain, and an anteroposterior tele-radiograph of the right lower and the right upper limb of every subject in the study was made in order to measure the lengths of the femur, tibia, fibula, humerus, cubitus and ulna. Pearson's regression formulae were obtained for both limbs. In males, the femur was found to be the most accurate predictor of stature (R = 0.851), whereas in females best results were obtained with the tibia (R0.876).

There are very few papers in forensic literature in which scapular dimensions allowing the forensic duty to estimate the living stature of skeletal remains. Using intact or fragmented scapulae, Campobasso *et al.* (1998) performed multiple regression analysis between the measurements taken from 80 scapulae (40 male and 40 female) belonging to a skeletal collection with anthropometric known data. Seven parameters (maximum length, maximum breadth, maximum acrocoracoid distance, length of acromion, maximum length of coracoid, length of glenoid cavity, width of glenoid cavity) were recorded. By statistical analysis, multiple and linear regressions were obtained. The results showed that living stature may be determined by using regression formulae of single or associated parameters taken from whole or fragmented scapulae. According to the authors, in the absence of intact or fragmented long bones, scapula sample can be reliably employed for the estimation of stature in forensic practice.

1.1.3 STATURE ESTIMATION FROM FRAGMENTARY SKELETAL ELEMENTS

A frequent obstacle to the proper analysis of prehistoric skeletal populations is a lack of a sample adequate for study. Most of the techniques available for the determination of various skeletal traits, such as age, sex, race, stature, etc. can be used only on well-preserved bones from relatively complete skeletons. Too often exhumed remains are in such fragmentary condition that few inferences of biological importance can be made, and attention is necessarily restricted in many cases to a small sample of cranial material. Krogman and Iscan (1986) have listed various researches on statural reconstruction carried out in different parts of the world. Of numerous studies cited by them, almost all pertain to complete long bones. But what should be done with broken or burned bones recovered in a fragmentary state from the crime scene? For such situations, they suggested the estimation of the total length of the bone from its fragments before using them in statural formulae.

One such method was reported by Müller (1935), who calculated the percent total lengths of various sections of three long bones. This original study was an analysis of skeletal material obtained from the osterreiches Beinhaus in Zellerndorf, the sample consisting of 100 humeri, 50 radii, and 100 tibiae.

Müller calculated five sections for the humerus, her selected lines of demarcation being (1) the most proximal point of the humerus, (2) the most inferior margin of the articular surface of the head, (3) the convergence of the muscle lines originating from the greater and lesser tubercles, (4) a transverse line passing through the proximal edge of the olecranon fossa, (5) a transverse line passing through the distal edge of the olecranon fossa, and (6) the most distal point of the humerus. The radius was divided into four sections, the lines of demarcation being (1) the most proximal point of the radius, (2) the inferior margin of the radial head, (3) a transverse line passing through the middle of the radial tuberosity, (4) the distal epiphyseal line, and (5) the most distal point of the radius.

The tibia was divided into seven sections, these being demarcated by (1) the most proximal point of the tibia, (2) the proximal epiphyseal line, (3) a transverse line passing through the most elevated point of the tuberosity, (4) a transverse line passing through the proximal end of the anterior crest of the shaft, (5) a transverse line passing through the point of smallest circumference of the shaft, (6) the inferior epiphyseal line, (7) the inferior articular surface of the tibia, and (8) the most distal point of the medial malleolus of the tibia. The mean percent total length and per cent standard deviation was then calculated for each section, allowing simple conversion to total length. The paper demonstrated that correlations between portions of long bones and their total lengths could be determined and provided a new direction to the study of skeletal material.

Steele and Mckern (1969) and Steele (1970) refined and expanded Müller's method by applying more up-to-date statistical procedures as well as stricter control of the sample. The sample utilized was recovered from sites located between the St. Francis and Mississippi rivers in northeastern Arkansas. Maximum and parallel lengths of the femur, humerus, and tibia were measured. They measured various linear segment lengths for the three bones to formulate regression equations for the estimation of bone lengths and stature respectively. Using two lower extremity bones as against one used by Müller (1935), Steele and Mckern (1969) and Steele (1970) employed different statistical procedures to enhance the accuracy in predicted bone length, as well as stature.

Hoaglund and Low (1980) studied the anatomy of the femoral neck and head, with comparative data from Caucasians and Hong Kong Chinese. The femoral neck was anteverted from the transcondylar plane on the average 8 degrees in the adult measurements that they made of femora from cadavers of Caucasians; the anteversion angle averaged 7.0 degree in males (range, - 2 degrees to 35 degrees) and 10.0 degrees in females (range, -2 degrees to 25 degrees). Using similar techniques on cadavers of Hong Kong Chinese, they found that the average in males was 14.0 degrees (range, - 4 degrees to 36 degrees) and 16.0 degrees in females (range, 7 degrees to 28 degrees). Specimens were found where there was retroversion of the femora. Based on the study, there were significant differences in the measurements of the head, neck and proximal femoral shaft of average normal Caucasian and Hong Kong Chinese people.

In India, Mysorkar *et al.* (1980, 1982) used fragmentary measures of radius, humerus and femur for estimating stature on the one hand while on the other Chandra and Nath (1984, 1985) used a single fragmentary measure to formulate multiplication factors for estimating humeral and femoral lengths.

In Germany, Rother *et al.* (1985) made a study to investigate if the relations between individual segments of long tubular bones are also dependent upon overall bone length. For these investigations, use was made of 356 human femora of unknown sex, which were obtained from the bone collection of the Institute of Anatomy and 70 human humeri of known sex, which were obtained from the Institute of Forensic Medicine and Criminology, Karl Marx University at Leipzig, and which have already been measured in connection with problems of forensic osteology. Relations between defined partial lengths were established. The strength of relationship was additionally determined by means of correlation and regression analyses. They showed that the relative proportion of 'the distance between the proximal point of the intercondylar fossa of the femur and the distal point of the medial condyle of the femur' and 'the distance between the proximal point of the greater trochanter and the midpoint of the lesser trochanter' constantly decreased with the overall length of femur. The quotient of diaphyseal size and bone length decreased as length of the humerus increased. The proportion of compacta in the total cross-sectional area in the mid-diaphysis became greater and greater as length of the humerus increased. The total cross-sectional area and the compacta cross-sectional area of the middle of the humeral diaphysis tended to change with the overall bone length in that longer female and male humerii had larger total cross-sectional and compacta cross-sectional areas.

In Japan, morphological studies of the upper end of the femur was conducted by Komatsu (1986). The mediolateral diameters (MLD) and the anteroposterior diameters (APD) of the head and the upper end of femora excised from autopsy cases were measured in the moist state and analysed. Multiple regression analysis of the relation between stature and the diameters of the femoral head and neck showed that femoral head diameters were related most closely to the stature. The mean values of the diameters of the femoral head and neck exhibited significant sexual differences (P less than 0.01). When the right and left measurements were compared, the femoral head diameters tended to show a significant difference (P less than 0.1); there was also a significant difference in the subcapital diameters (P less than 0.05).

Simmons *et al.* (1990) presented a study to assess the feasibility of stature estimation using small fragments of the femur. In their approach to improve the methods by earlier workers (Steele and Mckern, 1969; Steele, 1970) which are plagued by the difficulty of identifying the anatomical landmarks, they used standard, clearly defined measurements taken on the distal, proximal, and midshaft regions of the bone. A sample of 200 males and females, blacks and whites (total sample = 800), was obtained from the Terry Collection. They took seven measurements on the femur, which are standard and defined in Martin (1957). They modified the midshaft diameter to a minimum transverse shaft diameter in order to avoid the necessity of locating a midpoint on a fragment. Equations for the prediction of stature were generated in two ways. First, stature estimation was performed by the usual method of regressing stature onto bone measurements. Second, because the Terry

Collection records do not always list the cadaver stature of the individual, maximum femur length was also regressed onto bone measurements. They presented the means and standard deviations for each of the segments measured as well as correlations for these measurements with femur length and cadaver stature. The proximal femur breadth (VHA) showed the highest correlation in males. In females, however, several other measurements were more highly correlated. In general, correlations rarely exceeded 0.65. It was evident that lateral condyle height had the higher correlation with stature and femur length and is to be preferred as the predictor variable when both condyles are present. Regression equations for estimating height and femur length from various fragments were presented. The three variables which showed the highest and most consistent correlations with maximum femur length and stature were upper breadth of the femur (VHA), vertical diameter of the femur head (VHD), and posterior height of the fibular condyle (LCH). The method of femur length and stature estimation presented by Simmons *et al.* (1990) has several advantages over previous attempts. First, the anatomical landmarks, by which the various measurements were defined, are standard, well defined, and easy to locate. Second, the standard errors of estimates were equal to or lower than those presented by Steele (1970) for some of his smaller segments. And third, because the sample size used in the study was approximately four times that used by Steele (1970), the regression equations were more accurately estimated. Finally, they submitted that the Terry Collection skeletons were drawn from a population considerably smaller than contemporary Americans. Therefore, they suggested these results should be viewed more as indicative of the feasibility of the technique than as providing formulae applicable for forensic science work on contemporary people.

Badkur and Nath (1990) presented a study aimed at formulating linear and multilinear regression equations for the reconstruction of ulnar length and stature through eleven fragmentary measures pertaining to linear, transverse, sagittal and circumferential dimensions of the ulna bone. Data for the study, collected in 1985, comprised of 288 ulnae belonging to 82 male and 62 female skeletons assigned to the Medico-legal Institute, Bhopal, Madhya Pradesh, for detailed examination. The skeletons belonged to Indian males and females who were residents of the state of Madhya Pradesh in India. The skeletons were well documented for sex and stature and ranged in age between 20 and 35 years. The measurements were taken on well-macerated adult right and left ulnae with cartilage removed, after sufficient time to ensure thorough drying. Besides recording stature of each documented skeleton, the following twelve measurements were taken by one of the authors on all the 288 ulnae according to the techniques recommended by Martin and Saller (1959) and Bass (1971): Height of radial facet (HRF), height of ulnar tuberosity (HUT), maximum length (ML), Breadth of olecranon (BO), breadth of distal epiphysis (BDE), upper shaft diameter (USD), mid-shaft diameter (MSD), sagittal diameter (SD), and lower shaft diameter (LSD). The right and left sides revealed non-significant variations at 5% level of significance for all the twelve measures. The male ulnae exhibited greater dimensions for all the measurements than the female ones and the sex differences, as assessed through the t-test, were highly significant at 1% level of significance. Stature means also showed a highly significant sex difference like the twelve measurements of ulnae. Depending upon the relationship of the fragmentary bone measurements with ulnar length, various linear and multilinear regression equations had been computed for the estimation of bone length. The regression equations formulated for reconstruction of bone length revealed that the correlation coefficient (r) varies between 0.426 and 0.286 for males while it was sufficiently higher for females (between 0.603 and 0.350). The use of multilinear regression analysis demonstrated that a combination of four fragmentary measurements proved to be the most effective as the value of multiple correlation (R) was increased in both sexes compared to the values of simple correlation. Using maximum length and 11 fragmentary measurements of ulna, they computed linear regression equations for determination of stature in the two sexes separately. The correlation coefficient value (r) varied between 0.348 and 0.103 for males and is much higher for females, i.e. between 0.496 and 0.300, for different fragmentary measurements. However, the maximum ulnar length exhibited a much higher correlation with stature, i.e. 0.522 for males and 0.717 for females. Using multilinear regression analysis, the value of multiple correlation (R) increased to 0.409 for males and 0.548 for females in a combination of two fragmentary measurements. Multilinear regression analysis increased the accuracy in predicted stature in comparison to the linear ones.

Holland (1992) presented a paper to devise a technique for use on less-than-complete tibiae from which no reliable measurements of length can be obtained. A total of 116 left tibiae from the Hamann-Todd Collection at the Cleveland Museum of Natural History were measured. The tibiae were selected from 58 males and 58 females, distributed equally by race (black or white). The 116 tibiae were divided into two samples. Sample 1 (n = 100) was used to formulate the regression equations employed in the study, and sample 2 was employed as an independent test of equations' accuracy. Sample 2 consisted of 8 males and 8 females distributed equally by race. Neither sample controlled for age. Statures were taken from the Hamann-Todd files. These figures represent stature at time of death. Eight measurements of the proximal end of each tibia were taken to the nearest 0.1mm. using a vernier sliding caliper. One day later, 20 (20%) of the sample 1 tibias were remeasured, and the pool of measurement was culled to five, each having an intra-observer error of 3.5% or less. This level was selected arbitrarily as it proved to be a natural separation point. The five measurements retained were: biarticular breadth (BB), medial condyle articular width (MCW), medial condyle articular length (MCL), lateral condyle articular width (LCW), and lateral condyle articular length (LCL). Following measurement, simple and multiple linear-regression equations were formulated. Holland (1992) demonstrated that estimation of adult stature using the proximal end of the tibia is possible due to a linear relationship that holds between stature and the proximal end of the tibia (for example, biarticular breadth, $r = 0.82$). Analysis of the residuals suggested that the equations have a slight tendency to underestimate stature. Furthermore, estimates greater than 175 cm and less than 160 cm tended to produce larger residuals than estimates that fall between those values. Both trends were weak, however, and the overall pattern of residual values was random. Holland (1992) mentioned the restrictions that confine the study. Not only were the equations generated from a small sample (in comparison to that of Trotter and Gleser, for example) of morgue specimens, but also the sample was restricted to American blacks and whites. Therefore, the equations should be considered population – specific.

Steele's (1970) regression method for estimating femur and tibia length from fragmentary bones was tested by Jacobs (1992) on a sample of complete femora (female $n = 26$; male $n = 33$) and tibiae (female $n = 16$; male $n = 22$) from a number of European Mesolithic and Neolithic sites. According to Jacobs (1992), over half of the regression equations given by Steele for predicting maximum length of the bone from the length (s) of one or more of its constituent segments were shown to produce inaccurate predictions in the test sample. However, a closer evaluation of the results, including calculation of regression equations for the test sample itself, revealed that this inaccuracy did not derive from any inherent flaw in Steele's method. Rather, it was shown that differential distribution of maximum bone length among the various bone segments as defined by Steele might occur due to variation in muscular activity pattern and intensity. This argues for the retention of Steele's basic method, with care being taken to match closely the activity pattern typical of the sample from which regression equations are derived with that of the population to which the equations are to be applied.

In a study involving the skeletal identification of stature, Introna *et al.* (1993) performed multiple regression analysis between the measurements taken from 80 tibiae (40 male and 40 female) and the living stature of the subjects to whom the tibiae belonged to in life. The goal was to allow the forensic investigator to estimate the living stature by integral tibia fragments just using association or single tibia measurement. The regression equations obtained allow to estimate living stature from different associations of well-defined segments of tibia. This was a useful aid in forensic investigations, in Italy, where it may be necessary to ascertain the individual's height during his/her life from isolated fragmented or mixed skeletal remains.

Iscan *et al.* (1994) assessed skeletal change in the Japanese population and developed appropriate standards for determining sex from the tibia. Osteometric data were obtained from 84 Japanese skeletons located at Jikei Medical University, Tokyo. The collection was assembled from the anatomy dissecting room between 1960 – 1970. With a mean age of about 56 years for males and 51 for females, the sample represents individuals who lived through WW II. A total of seven tibial dimensions were obtained from the 84 skeletons. The length of the tibia had increased at least 10 mm in females but only a minimum of 4 mm in males from the prewar era. Their findings indicated two important changes: 1) post-war Japanese people are considerably larger than their predecessors, and 2) sexual dimorphism has decreased overtime. The research also reemphasized that dimensions like circumference and epiphyseal breadths are sometimes better indicators of sexual dimorphism than length. This finding agrees with observations of American whites in which the length did not contribute significantly when proximal epiphyseal breadth and circumference at the nutrient foramen were known (Iscan and Miller-Shaivitz, 1984). It also indicated racial differences in the skeleton, as length did contribute to the function for American blacks. They reminded forensic osteologists to be aware that a local sample may not necessarily represent the population at large, because diverse stresses may operate differently in specific geographic regions, thus creating microracial variation within a population. The authors therefore emphasized the need to update methods to reflect changes over time within a particular population, especially when they have been subjected to great changes in their environment.

Craig (1995) presented a study that documents a new method to determine race from the distal femur. Measurement of the angle between the intercondylar shelf and the posterior shaft of the femur (intercondylar shelf angle) revealed a relatively consistent and statistically significant difference between American whites and blacks. A restricted random sample of 200 white and 200 black patients was generated from the Hughston Orthopaedic Clinic in Columbus, Georgia, and additional restricted random sample of 100 of each race was obtained from the University of Tennessee Medical Center in Knoxville, Tennessee. Lateral radiographs were retrieved for all 600 patients. Radiographs from 177 individuals were excluded because of various factors. The final sample consisted of 423 individuals. The sample included 240 whites and 183 blacks, 235 males and 188 females. For the test of the intercondylar shelf angle, only one knee from each individual was analyzed. The overall white mean was 146 degrees and the black mean was 138 degrees. The overall mean for females was 142.58 degrees and the overall mean for males was 142.54 degrees. In order to test the hypothetical method of determining race from the intercondylar shelf angle, the same method of measurement was applied to a skeletal sample. A total of 67 individuals was randomly selected from the William Bass donated skeletal collection, and one femur was taken from each case. Since this was a relatively small sample, the author divided the method of analysis into two different components in an attempt to find the optimal method of analysis. The first test included 46.3% of the sample and only involved those individuals whose angle equal to or beyond the mean for each race. Those whose notch angle was 146 degrees or greater were classified as white. Those whose notch angle was 138 degrees or less were classified as black. Twenty-eight individuals, or 90% of the individuals were correctly classified. For the second test, the entire sample was used. The sectioning point for this test was 141 degrees. Individuals with a notch angle of 142 degrees or greater were classified as white and those with a notch angle of 141 degrees or less were classified as black. Fifty-seven individuals, 85% of the entire sample were correctly classified. Variations in the angle were not dependent on the size of the femur, nor is the angle affected by arthritis in the notch or by trauma to the articular surfaces. Even fragmentary femora can also be measured. Therefore, it is a non-invasive technique that can be used in skeletal cases as well as cases where there are intact soft tissues.

Vettivel *et al.* (1995) conducted a research, which showed the intertubercular sulcus (ITS) of the humerus as an indicator of handedness and humeral length. Measurements of the maximum width and depth of the ITS, angles of the medial and lateral walls with the floor of the ITS, as well as the length of the humerus in 100 right and 100 left matched, unpaired dry humeri of 100 adults from Southern India were statistically analyzed. The width and depth of the ITS were intercorrelated with the length of the humerus ($p<0.001$). Regression equations of the length of the humerus on width, depth, as well as width and depth of the ITS were derived.

Neck-shaft angle (NSA), neck length (NL), intertrochanteric apical axis length (ITAAL), and maximum vertical diameter of the femur head (VDH) were used by Prasad *et al.* (1996) as markers to estimate maximum femur length (FL). Adult dry femora (171), grouped into male (94) and female (77) and left (88) and right (83), and ranging in age from 25 to 55 were used for the study. The bones belonged to the subjects of the State of Tamil Nadu in Southern India and were obtained from a pool of bones available in the Department of Anatomy, Christian Medical College, Vellore. Correlation coefficients among FL and NSA, NL, ITAAL, and VDH were determined for the sexes, sides, and total. Length of femur significantly and positively correlated with those markers except for NSA of the right side. Simple linear regression models were derived for estimating femur length from the other dimensions. Finally, they concluded that their statistical explanation for validity suggests their models to be applicable to different populations.

Isaac *et al.* (1997) performed a study to (1) measure the neck-shaft angle, length of the neck, intertrochanteric apical axis length, maximum vertical diameter of the head, kinematic radius of the proximal femur, and maximum femoral length in the adult femora, (2) test for significant intercorrelation between these parameters, (3) regress every two of the significantly correlated parameters, and (4) determine the required size of a parameter or parameters from the regression of the neck-shaft angle against the other correlated parameters to rectify the defective angle to normal. A total of 171 South Indian adult, unpaired, left and right dry femora were studied. The bones ranged in age from 25 to 55 years. There was no significant side difference in all the parameters studied. The parameters significantly intercorrelated but the neck-shaft angle and kinematic radius did not correlate with the intertrochanteric apical axis length. Simple regression of the correlated parameters with each other were presented. Multiple regression of the neck-shaft angle against the other correlated parameters of the proximal end of the femur suggested that only the length of the neck was significant to estimate the neck-shaft angle. The angle showed a strong correlation with length of the neck. Therefore, based on the results of their study, length of the neck was the best predictor of the neck-shaft angle.

A study on estimation of length of calcaneum and talus from their bony markers was done by Koshy *et al.* (2002) on contemporary South Indian population. A total of 110 calcanei (55 right and 55 left), and 70 tali (35 right and 35 left), all unpaired and dry were used. Maximum anteroposterior length of the bone, and linear measurements of the other bony markers were measured. Bony markers of calcaneum were maximum anteroposterior length, maximum transverse width, length, width and depth of groove on the sustentaculum tali, and length, width and depth of the sulcus calcanei. Bony markers of talus were maximum anteroposterior length, maximum transverse width, length and width of articular surface for the lateral malleolus, length and width of articular surface for the medial malleolus, vertical width and transverse width of articular surface of the head, width and depth of groove for tendon of the flexor hallucis longus, and length, width and depth of the sulcus tali. Simple regression suggested that maximum length of the calcaneum regressed significantly with maximum transverse width, length and depth of groove on the sustenataculum tali and length, width and depth of the sulcus calcanei and that maximum length of the talus regressed significantly with maximum transverse width, length and width of the lateral articular surface, length of the medial articular surface, vertical and transverse diameters of the head and depth of the sulcus tali. Maximum length of calcaneum and talus were derived from the regression values, to predict the stature of the person from available tables.

1.1.4 SECULAR TREND IN HUMAN PHYSICAL GROWTH

The term secular trend is generally applied to such positive changes that have become manifested in a faster growth, an earlier maturation of children, a taller stature of adults, etc. (Suzanne and Bodzsár, 1998). However negative tendencies were also described, when the living conditions have markedly decreased for longer periods. Consequently secular changes in growth and development are ways to observe socioeconomic conditions of populations as well as their state of health.

A series of height and body mass means for Budapest children in Hungary from 1930 through 1990 showed a significant trend of increase (Bodzsár, 1998).

Secular trends in body height, however common, run at different rates and even in opposite directions in various populations. The standard explanation is that direction and tempo of the trend are reflections of changes in the socioeconomic situation. Henneberg and Van Den Berg (1990) presented a research aimed at testing this hypothesis by examining trends in different socioeconomic groups living in the same country. Their observations on affluent South Africans of European extraction (AE) and on Polish medical students were compared with the data on statures of other affluent and poor peoples from the two countries measured at various dates during the 19thb and 20th centuries. The overall direction among native South Africans was positive with a slow rate (0.24 cm/decade for 72 "Negroid" male groups and 0.48 cm/decade for 28 Khoisan male samples). Magnitude of the trend among adult AE (0.41 cm/decade for females, 0.59 for males) did not differ significantly from that among natives. The rate of trend among AE was much lower than that in their countries of origin (mainly Holland and Britain). The trend among AE medical students was markedly weaker than the trend among Polish medical students (1.21 cm/decade), who in turn paralleled Polish general conscripts (1.24 cm/decade). They concluded that the explanation of the secular trend as being an ecosensitive response of individuals to changing levels of well-being is insufficient.

Relethford and Lees (1981) used cross-sectional data, consisting of anthropometric measurements for 347 adult males and 261 adult females of Western Ireland measured during the 1930's, to determine the effects of ageing and secular change upon stature. Estimates of statural loss due to aging were obtained using partial regression of stature on age while controlling subischial length, and regression of the difference between observed stature and maximum predicted stature on age. Males showed the effects of aging to a greater extent than did females. After correction for the effects of aging, the adjusted values of stature were progressed on age to estimate secular trend of stature. For males, there was a general increase of stature with time, excepting those born around 1878, while females generally showed random variation with time. Both male and female adjusted stature decreased sharply around 1878 from which alternative historical explanations are proposed, relating to differential migration and survival.

McCullough (1982) studied secular trend for stature in adult male Yucatec Maya to 1968. Statures for 64 adult male Yucatec (18+ years old, sons of campesinos) were measured in 1968 and compared with mean statures presented in results of previous studies. There were no significant changes in mean stature since 1895. If the sample is divided into 5-year age groups, no secular trend was evident. Using osteological information from as early as the Late pre-classic, stature of adult Maya males has decreased 119 mm in a little more than 20 centuries (-0.06cm. / decade). Comparing the results with measurement from other Mesoamerican groups, only one—the Otomi – showed evidence of significant secular change. It is possible that modern economical development schemes in Mesoamerica are too recent or ineffective to have had an effect on stature.

Ohyama *et al.* (1987) presented a study on some secular changes in body height and proportion of Japanese medical students. The data used in the report were collected during the periods 1961 – 62, 1966 – 67, 1970 – 71, 1975 – 76, and 1980 – 81. A total of 1065 medical students (997 males and 68 females) were included in the surveys. Excluding men aged 26 and over, the number of male students for each successive 2 years was 137 (1961 – 62), 109 (1966 – 67), 202 (1970 – 71), 183 (1975 – 76), and 107 (1980 – 81). These numbers accounted for 74% of the total number of male students between 1961 and 1981. Ages ranged from 22 to 25, with a mean of 22.4 years. Medical students at Kyushu University generally came from the Southern part of Japan, and the social class of these students was relatively high. In addition to standing height, the height of spina iliaca anterior and superior and the height of the upper margin of synostosis pubis were measured to the nearest millimeter, using Martin's metal anthropometer (Martin, 1928). From these samples, the authors analyzed annual changes in standing height, leg length, leg length x 100 / standing height, and sitting height x 100 / standing height among Japanese medical students. The data were tested for statistical significance. For comparable data on the general population, they used the corresponding average measurements of 22 year old men published in the annual report of the Japanese Ministry of Health and Welfare for the years 1961 to 1981. The sitting height / standing height ratio showed a downward trend with slight variation. The difference in standing height between medical students and the general population had lessened year by year. Over the 20 years, standing height increased by 3.3 cm and leg length by 2.4 cm. Leg length x 100 / standing height increased by 1.0%, the difference between the two groups being statistically significant ($p<0.01$).

Therefore, the increase in standing height derived not from a proportional increase in each part of the body, but rather from an increase in leg length. They divided each of the samples in 1961-62 and in 1980 – 81 into four subgroups by quartiles in the distribution of height (very low height group, low height group, high height group, and very high height group). They obtained the secular change of leg length x 100/standing height being significantly increased among both high and very high height group members during the interval of 20 years, with $p<0.05$ and $p<0.01$, respectively. The secular increase in standing height noted in the study was particularly prominent during the 10 years following World War II, but this trend was somewhat suppressed during the subsequent 10 years. The authors postulated that the increase in height was related to a particular increase in leg length, and indeed members of the younger generation did have longer legs. The suppressed increase in medical students' heights after 1970-71 was considered to be due to a lack of the increase in leg length; however, they were unable to find a plausible explanation for the cessation of the trend of increasing leg length after 1970-71. In terms of explaining a slight but still continuing increase in height despite the cessation of increase in leg length, a secular change in sitting height might have occurred after 1970-71; owing to the decline in the rate of increase in height of the medical students, differences between the height of medical students and members of the corresponding general population of the same age had diminished. This phenomenon in medical students seemed to be consistent with the finding that the difference in socioeconomic status between medical students and the corresponding general population had narrowed during the 20 years. Comparison of the two groups suggested that an improvement in nutrition and socioeconomic status might be partly responsible for the secular change in height in the Japanese. However, on the other hand, the findings, especially for the latter 10 years, also showed that the social class of medical students was still rather high in 1981 compared with that of the general population. Yet the difference in standing height of the two groups was practically nil in the same year. This would suggest that socioeconomic status no longer affects human health and physical growth, once it reaches a level adequate to provide a comfortable environment, such as proper housing and medical care. Nutrition also appears to affect the secular increase in physical growth, in terms of energy ratio of protein, fats, and carbohydrate, which changed remarkably in Japanese diet. Several other factors had been considered as possible explanations for the increasing change in height detected in each observed population, including decrease in family size or better living standards. The authors submitted that the secular increase in height noted in the Japanese population is not fully explained, but it is of particular interest that the increase in leg length was more prominent among subgroups of taller individuals. This phenomenon was evident despite a more common socioeconomic status among the medical students and was close to that of the general population. According to the authors, their findings suggested that the body shape of the Japanese might eventually approach that of American and European people, if the trend toward increased height continued.

Although it is widely accepted that persons become shorter when they grow older, most estimates of the rate of decline are based largely on cross-sectional studies and are confound to secular changes and individual variation. Chandler and Bock (1991) used a mixed series of longitudinal physical measurements obtained by the Busselton Population Studies Group, for the entire adult population of Busselton, Western Australia. All persons in the sample who had a minimum of three measurements at 3-year intervals were included in the analysis, regardless of health. Random regression analysis of the individual heights and age data was used to estimate the expected rate of decrease of stature with age. A significant sex difference was found with females declining at a greater rate than males, particularly after the age of 40.

Stature – estimation formulae in common use are those of Trotter and Gleser. Their formulae for females are based on Terry Collection skeletons. These skeletons are from people who died in the early 1900s. Jantz (1992) argued that because there had been considerable change in body size since then, it is possible that the Trotter and Gleser formulae are inappropriate for modern forensic-science application. Accordingly, the author tested the Trotter and Gleser female formulae using data from the Forensic Data Bank at the University of Tennessee. For whites, the femur and tibia yielded stature estimates differing from one another by about 3 cm. Using femur and tibia lengths from modern forensic cases and modern height data from anthropometric surveys, new regression intercepts were calculated for Trotter and Gleser's female formulae. According to the author, the new intercepts improve the performance of the formulae on modern individuals. The Trotter and Gleser formulae for black females required no adjustment. Finally the author concluded that both blacks and whites had experienced a secular increase in bone length, but whites have experienced a change in proportions as well.

Meadows and Jantz (1995) examined the allometric secular changes of the six long limb bones for white and black males from the mid 1800s to the 1970s. Long bone lengths and statures for white and black males available from the Terry Collection and from WWII Casualties were used. The measurements included the maximum lengths of the humerus, radius, and ulna for the upper limb, and maximum and bicondylar lengths for the femur, maximum length and ordinary or physiological length of the tibia, and maximum length of the fibula. The authors used two types of analyses to reveal secular changes. First, allometry scaling coefficients were derived by regressing *log* bone length on to *log* stature. These showed that the femur, tibia and fibula were positively allometric with stature, while the humerus, radius and ulna were isometric. The lower limb bones were more positively allometric in the WW II sample than in the Terry sample. Second, secular changes in length of femur and tibia and in the tibia/femur ratio were evaluated using modern forensic cases in addition to the Terry and WW II samples. This analysis showed that secular increase in lower limb bone length is accompanied by relatively longer tibiae. They suggested that secular changes in proportion may render stature formulae based on nineteenth century samples, such as the Terry Collection, inappropriate for modern forensic cases. The positive allometry of the lower limb bones argues against using simple femur/stature ratio, which assumes constant proportionality, as an alternative to regression equations.

Jantz and Jantz (1999) examined secular change in long bone lengths and allometry of Americans dating from the mid-19th century to the 1970's. Skeletal samples were derived from the Huntington Collection, the Terry Collection, World War II casualties, and the Forensic Anthropology Data Bank. Regression of bone length on years of birth allowed evaluation of the secular change in bone length. Size was computed as the geometric mean of all bone lengths and shape as the ratio of each bone to size. The variables were then regressed on year of birth, allowing evaluation of allometric secular change. The results revealed a pattern of change that can be summarized as follows: male secular change is stronger than female; lower limb bone secular change was more pronounced than upper limb bone change; and distal bones changed more than proximal bones, particularly, in the lower limb. In males, white changes were uniformly higher than black but these differences did not rise to the level of statistical significance. Environmental forces, such as nutrition and disease, are the usual causes of secular changes in overall size. The paper showed that changes in long bone proportions also result from these same environmental factors. Moreover, the changes of body proportion also result from these same environmental factors and these changes of body proportion are likely to be due to allometric consequences of growth changes that occur early in life.

Stature, maturation variation and secular trends in forensic anthropology were discussed by Klepinger (2001). A twentieth century trend for increased stature has received considerable attention in the forensic literature with regard to its effects on stature estimation, but according to Klepinger a secular trend for earlier maturation has received little attention. Current evidence indicates that within populations with similar climatic adaptation, truncation or extension of the same trajectory of ontogenetic allometry accounts for the secular trend and the within cohort stature variation, as well as the scaling of limb proportion to stature and intralimb proportions. Since secular increase is small compared to interindividual variation, the Trotter and Gleser formulae are still appropriate as long as the 95% confidence intervals are applied. A secular trend for increasing childhood and adolescent obesity is associated with a trend for accelerated skeletal maturation, but does not predict a consistent direction or a quantitative correction for traditional standards. Secular trends for increased stature and earlier maturation are overshadowed by increasing non-secular intrapopulational variation (Klepinger, 2001).

1.1.5 PROBLEMS IN STATURE ASSESSMENT AND STATISTICAL CONSIDERATIONS

Researchers have long appreciated the significant relationship between body size and an animal's overall adaptive strategy and life history. However, much more emphasis has been placed on interpreting body size than the actual calculation of it. One measure of size that is especially important for human evolutionary studies is stature. Despite a long history of investigation, stature estimation remains plagued by two methodological problems: (1) the choice of the statistical estimator, and (2) the choice of the reference population from which to derive the parameters. The work by Hens *et al.* (2000) addressed both of these problems in estimating stature for fossil hominids, with special reference to A.L. 288-1 (*Australopithecus afarensis*) and WT15000 (*Homo erectus*). Three reference samples of known stature with maximum humerus and femur lengths were used in the study: a large (n = 2209) human sample from North America, a smaller sample of modern human pygmies (n=19) from Africa, and a sample of wild-collected African great apes (n = 85). Five regression techniques were used to estimate stature in the hominids using both univariate and multivariate parameters derived from the reference samples: classical calibration, inverse calibration, major axis, reduced major axis and the zero-intercept ratio model. The authors also explored a new diagnostic test extrapolation and allometric differences with multivariate data, and calculated 95% confidence intervals to examine the range of variation in estimates for A.L. 288-1, WT 15000 and the new Bouri hominid contemporary with [corrected *Australopithecus garhi*]. Results frequently varied depending on whether the data are univariate or multivariate. Unique limb proportions and fragmented remains complicate the choice of estimator. The authors were usually left with the classical calibrator as the best choice. It is the maximum likelihood estimator that performed best overall, especially in scenarios where extrapolation occurred away from the mean of the reference sample. They concluded that the new diagnostic appears to be a quick and efficient way to determine at the outset whether extrapolation exists in size and/or shape of the long bones between the reference sample and the target specimen.

Many applied problems in physical anthropology involve estimation of an unobservable quantity (such as age at death or stature) from quantities that are observable. Konigsberg *et al.* (1998) discussed the rationales for making estimations on isolated bones taking stature estimation from femoral and humerus length as an example. The entirety of their discussion can be placed within the context of calibration problems, where large calibration sample was used to estimate an unobservable quantity for a single skeleton. Taking a calibration approach, the problem highlighted the essentially Bayesian versus maximum likelihood nature of the question of stature estimation. On the basis of both theoretical arguments and practical examples, they showed that inverse calibration (regression of stature on bone length) is generally preferred when the stature distribution for a reference sample forms a reasonable prior, while classical calibration (regression of bone length on stature followed by solving for stature) is preferred when there is reason to suspect that the estimated stature can be extrapolation beyond the useful limits of the reference sample statures. The choice between these two approaches amounts to the decision to use either a Bayesian or a maximum likelihood method.

In 1953, Keen discussed thoroughly the relevant literature on estimation of stature from long bones and explained the errors involved in regression equations. The error in using regression formulae for reconstruction of stature from long bones is statistically expressed as the 'standard error of the estimate'. This is the measurement of the error likely to be made in reconstructing the stature of an individual known to belong to a population similar to that from which the regression formula was calculated. To clarify the use of the standard error of the estimate (S.E.E.), the author presented an example. "The S.E.E. of Pearson's formula for an estimate of stature from the length of the femur is 3.2 cm. Suppose the best estimate of the stature is 180 cm. The difference between the true stature and this estimate may be expected to exceed the limits of:

± 3.2 cm, i.e. 176.8 – 183.2cm. in 1 case out of 3;
± 6.4 cm, i.e. 173.6 – 186.4 cm. in 1 case out of 22;
± 8.0 cm, i.e. 172.0 – 188.0 cm. in 1 case out of 100;
± 9.6 cm, i.e. 170.4 – 189.6 cm. in 3 cases out of 1000

(The second, third and fourth lines express the chances of exceeding the limits of ± 2 , 2.5, and 3 times the S.E.E. respectively). It is clearly not safe to rely on the odds of 2:1 expressed in the first line, and it is common statistical practice to regard any deviation of less than twice the standard error as being due to chance." In other words, the estimate made in this hypothetical case cannot be expressed in terms more precise than: 'The individual from whom the femur was derived is unlikely to have been taller than 186.4 cm (6ft 1 ½ in) or shorter than 173.6 cm (5ft 8 ½ in)' . No opinion could be offered on the exclusion of any individual whose stature fell within this range of 5 inches.

Errors naturally increase when formulae are used on subjects from different population groups. In addition the results will be biased in the direction caused by the differences in body proportions between the groups. Stevenson (1929) found that Pearson's formulae underestimated the stature of his Chinese subjects by 4.5 cm on the average. Comparisons between the two American groups, Whites and Blacks, are found in the two American studies. Trotter and Gleser (1952) showed that in their subjects the Blacks 'have longer limb bones relative to their stature than do whites', in addition to the well known greater length of the forearms and the legs relative to the arms and the thighs. Therefore when they calculated the mean stature of their Black males using their White male formula for the femur, they overestimated it by 4.3 cm; the corresponding figure from Depertuis and Hadden's study was 2.6 cm. The bias was in the opposite direction, i.e. from calculating the mean stature of their White male group using their Black male formula for the femur, was 3.8 and 3.6 cm respectively. Such a bias significantly increases the standard error of the estimate, though naturally the bulk of the errors occur in the direction indicated by the bias.

Keen (1953) recommended that in South Africa, where no figures for local populations were available at the time, all one could do was to use Trotter and Gleser's two sets of formulae, bearing the chances of greater error and possible bias firmly in mind when drawing up reports and giving evidence.

Lundy (1985) discussed the mathematical and anatomical methods of estimating living stature from long limb bones. The author briefly discussed the mathematical methods developed by Rollet (1889), Manouvrier (1892), Pearson (1899), Dupertuis and Hadden (1951), and Trotter and Gleser (1952). Then Lundy (1985) presented a detailed description of the Anatomical method as developed by Dwight (1894) and a variation of which was developed by Fully (1956). The author stated that while Trotter and Gleser's (1952) formulae for American Blacks, Whites, and Mongoloids were accurate and widely used, there were potential sources of error. Lundy (1985) stated that "We do not know how accurately the statures of American servicemen were measured, nor do we know if cadaver length differs from living stature always in the same manner." Snow and Williams (1971) reported finding considerable variation in the premortem statural measurements of a single individual taken from records of several police agencies where he had been measured upon arrest. The mathematical method is based upon the proportion of certain bones to height. It does not take into consideration the differing proportions of trunk length to total stature as described by Todd and Lindala (1928) and Hunt (1958). Lundy argued that the anatomical method, by including spine length when measuring skeletal height addresses this source of variation and is therefore, more accurate than the mathematical method. The correction factor added to the skeletal height when using the anatomical method compensates for the thickness of the soft tissues at the scalp, soles of the feet, and the cartilages at the joints. There is no evidence that these differ to any significant degree from one population to another. Wells (1931) in his study of the foot of the South African native, pointed out that while he found differences in the sole of the foot between Negroes and whites, these differences were in the arch of the foot and not at the weight-bearing points. Thus, the correction factors put forth by Fully (1956) should be reliable in all populations, and indeed, they were found to be accurate in the South African Black (Lundy, 1983; Lundy, 1984). One drawback to the anatomical method is that it requires a nearly complete skeleton to determine skeletal height. According to the author's experience in forensic cases, a complete skeleton is the exception rather than the rule. Fully and Pineau (1960) did address the issue of postmortem missing pre-sacral vertebrae, and Lundy (1984) addressed the issue in the South African Black. The anatomical method also makes it possible to regress individual long bones against skeletal height and derive stature estimation equations for skeletal samples lacking living statures or cadaver lengths (Lundy, 1983; Lundy, 1984). The author concluded that while the anatomical method is preferable, it will be the condition of the remains which entails the use of the anatomical or mathematical method. In forensic cases, when one has a nearly complete skeleton, the anatomical method is preferable to the mathematical method.

Regression equations for the estimation of stature from long bones, although derived from modern human populations are frequently applied to early hominids. In fact, some of these equations had even been recommended or especially created to be applied to Australopithecus remains. Geissmann (1986) applied 4 sets of regression and correlation formulae, recurrent in anthropological and medico-legal literature to bones of the Pliocene hominid A.L. 288-1 ("Lucy"), in order to assess which, if any, could be considered suitable for stature reconstruction in 'gracile' australopithecines. Virtually every method based on regression equations overestimates stature as compared with the estimate based on reconstruction of the preserved skeletal parts. In addition, most methods failed to give consistent results with data from different limb segments. None of the sets of regression formulae tested could be recommended as a reliable means of stature estimation in 'gracile' australopithecines.

Problems in estimating stature from skeletal remains are enough analysed in anthropology. Certainly, a great number of statements exist. Wurm and Leimeister (1986) attempted to study the problems of recommendability and comparability of these statements. They searched for reasons for these omissions and the neglect of the fact that physical contributions differed with historical and geographical aspects. Therefore, these authors presented some basic problems in estimating stature and gave some aids for better comparability and recommendability.

Jungers (1988) provided new stature estimates for A.L. 288-1 (*Australopithecus afarensis*) based on (1) the relationship between femur length and stature in samples of human pygmies and pygmy chimpanzees and (2) model I regression alternatives to standard least – squares method. Estimates from the two samples were very similar and converted on a value of approximately 3'6" for "Lucy". The results were compared to prior estimates and extended to other small-bodied hominids such as STS-14 and O.H.62. A new foot-stature ratio was also estimated for A.L. 288-I, and its potential biomechanical significance for gait was evaluated in comparison to other groups.

Although Fully's (1956) anatomical method had been advocated by Stewart (1979) and Lundy (1985), its use seems rare among forensic anthropologists. This might be due to the paucity of forensic science cases in which enough remains are present to employ the method, and it is more complicated and time-consuming than using Trotter and Gleser's (1958) equations. Lundy (1988a) got the opportunity to apply Fully's anatomical method to three military cases where sufficient skeletal material was available. He presented the results obtained using the anatomical method on these three cases and compared with stature estimates obtained using Trotter and Gleser (1958) formulae. Lundy (1988a) noted that the reliability of antemortem statures had been questioned by Snow and Williams (1971) and by Willey and Falsetti (1987). The measurements and completion of the anthropometric form were under the direct supervision of a physician and the form becomes part of the aviator's permanent record. Hence, the recorded statures for the sample discussed in the paper were far more reliable than those addressed by Snow and Williams (1971) and by Willey and Falsetti (1987). The estimates of stature based upon the anatomical method vary from the recorded heights by a margin of 0.1 to 0.8 in. (0.254 to 2.032 cm). The Trotter and Gleser (1958) formula provided one estimate, in which the recorded stature did not fall within the estimated range, and the other two central tendencies of estimate varied from the recorded data by margins of 0.9 and 0.3 in (2.286 to 0.762 cm). The data indicated that in the three cases, the anatomical method was as accurate as the so-called mathematical method, and in one case, more accurate. In conclusion, Lundy (1988a) stated that neither the mathematical nor the anatomical method should be expected to provide more than an estimate of living height, but obviously, the more accurate we can be the better. While the application of the anatomical method is limited to those few cases where a nearly complete skeleton is available, preliminary indications are that it may be worth the time and effort to try Fully's anatomical method when such a case presents itself.

Lundy (1988b) presented a paper which discussed the possible effects upon stature estimates of a sacralized sixth lumbar vertebra when both the anatomical method and standard equations are used to estimate stature. The example case was that of a Black U.S. Navy aviation officer, shot down during the Vietnam War. The skeletal remains were sufficiently complete to utilize Fully's anatomical method to estimate living stature. An accurate record of antemortem height was listed on the subject's anthropometric form. Examination of the remains revealed a congenitally sacralized sixth lumbar vertebra with S1 in the position of second sacral segment. Stature was estimated using both the anatomical method and Trotter and Gleser's (1958; 1970) formulae. The anatomical method stature estimate without the height of S1 differed from the recorded stature by 1.26 in (3.2 cm), while the estimated stature including the height of S1 was identical to the recorded antemortem stature of the individual. The estimate based upon Trotter and Gleser's formula provided a central tendency differing from the recorded stature by 1.10 in. (2.79 cm), but within the estimated range of the equation (± 1.39 in.) [3.53 cm]. This estimate could be improved by adding the height of L6 to it. Lundy (1988b) suggested that when one is confronted with a sacralized L6, articulating the pelvis may provide a clue as to whether to include the height of the actual S1 in the estimate or not. "View the pelvis from the front with the long axis of the pubic symphysis perpendicular to the line of vision. Tilting the pelvis into approximate anatomical position seems the best way to determine the relationship between the S1-S2 junction and the superior margin of the acetabulum. In the normal pelvis, the S1-S2 junction lies considerably above the superior margin of the acetabulum. If, in the unknown pelvis, both the sixth lumbar and the actual S1 segments lie above the superior margin of the acetabulum, then the height of S1 should be included in the calculations. If not, then one probably should not include the height of S1." Finally, the author concluded that in cases presenting a sacralized lumbar vertebra where Trotter and Gleser's or similar stature estimation formulae are used, adding the height of the extra vertebra might enhance the accuracy of the stature estimate.

Sciulli *et al.* (1990) investigated stature estimation techniques in a sample of 64 (35 male, 29 female) prehistoric Native Americans from Ohio. Because living stature was unknown for the individuals, they used Fully's (1956) anatomical method to provide the best estimates of living stature. Comparison of regression equations commonly used for stature estimation in prehistoric Eastern Woodland Native American population developed for East Asian and East Asian-derived populations (using lower extremity components), showed that the commonly used equations consistently yielded stature estimates of 2 to 8 cm in excess of the best estimates from Fully's method. Based on the skeletal height measures of the 64 individuals in the sample, they developed regression equations for estimation of stature. These equations yielded stature estimates virtually identical to estimates from Fully's method and the authors pointed out that they might be useful for stature reconstruction in other prehistoric Eastern Woodland Native American populations.

Feldesman *et al.* (1990) evaluated the femur / stature ratio in 51 different "populations" of contemporary human (n = 13,149) samples from all over the world. They found that the mean ratio of femur length to stature in these populations was 26.74%, with a very restricted range of variation. When they compared mean femur / stature ratios of males and females, there were no statistically significant differences. ANOVA performed on a naive grouping of samples into "whites," "blacks," and "Asians" indicated that there were significant racial differences (P less than 0.001). When they subjected these groups to Tuckey's HSD procedure (a post-hoc test), they found that "blacks" were responsible for the significant ANOVA, being significantly (P less than 0.005) different from the other ethnic groups. "Whites" and "Asians" were not significantly different (P = 0.067) under the conditions of their analysis, although all the racial comparisons might be suspect given the small sample sizes. They tested the efficiency of the ratio in three situations: predicting stature of repatriated white Vietnam Veterans; predicting stature in a random sample of South African blacks (of known stature), and predicting the stature of a single AkkA pygmy. In the first and third cases, the femur / stature ratio does better than the traditionally recommended regression equations, while in the second case the predictions from the femur / stature ratio were less accurate than from the appropriate regression equations. These results encouraged the authors to apply this ratio to mid- and late- Pleistocene fossil hominids, where the choice of reference population for stature estimate continues to trouble workers. They estimated stature for a sizeable number of *Homo-erectus* (HE), Early *Neandertal* (EN), Near Eastern *Neandertal* (NEN), and Early Anatomically Modern *Homo Sapiens* (EAMHS) by using the simple relationship: Stature (cm) = femur length (cm) * 100/26.74.

The results showed that HE fossils were slightly taller on average than either EN or NEN samples, which did not differ significantly in stature, while EAMHS fossils were significantly taller than all three earlier groups. The stature estimates by the authors for these fossils differed from previously published estimates based on sample – specific regression – based formulae.

Formicola (1993) discussed the problem of reliability related to stature reconstruction from long bones in ancient population samples. Stature estimates provided by the application of the anatomical method of Fully and Pineau (1960) to well preserved

Neolithic skeletons (39 males and 27 females) from seven different European countries were compared with those drawn from lower-extremity components by means of regression equations commonly used to predict stature of earlier European populations. The analysis of data, carried out with reference both to the sample of origin of the skeletons and to stature classes, suggested that the equations of Pearson (1899) and Trotter and Gleser for Blacks (1952) yielded very good estimates in female samples, leading to errors below 2 cm in most of the cases. These equations and those of Olivier et al. (1978), proved useful for stature reconstruction in males too, with the exception of very low (below 154 cm) and very tall (over 179 cm) individuals. Formulae of Breitinger (1938) gave values consistent with those resulting from the anatomical method only within a range including medium-high stature. The Trotter and Gleser formulae for whites (1952) yielded very unsatisfactory evaluations, except in specimens taller than 180 cm, and usually overestimate stature both in male and in female skeletons. The results obtained from the long bones by means of alternative approaches to the least-squares regression formulae (Model II regression, and femur/stature ratio) and their efficacy in predicting stature of the samples was discussed in the paper.

Trotter and Gleser's (1952) stature estimation formulae, based on skeletons of the Terry collection and on WW II casualties, have been widely used in forensic work. Jantz *et al.* (1995) stated that their work with the Terry and WW II data yielded tibia lengths too short compared to other data sets. Using Trotter's original measurements, they discovered that Trotter consistently mismeasured the tibia. Contrary to standard practice and her own definitions, Trotter omitted the malleolus from the measurement. Trotter's measurements of the tibia were 10 to 12 mm shorter than they should have been, resulting in stature estimations averaging 2.5 to 3.0 cm too great when the formulae are used with properly measured tibia. The authors also examined tibia lengths of Korean War Casualties, which were measured by technicians rather than Trotter. Korean tibia measurements were also too short, but by a smaller amount than Terry and WW II. Jantz *et al.* (1995) recommended that estimation of stature from Trotter and Gleser's tibia formulae is to be avoided if possible. If necessary, the 1952 formulae could be used with tibia measured in the same manner that Trotter measured, excluding the malleolus.

Formicola and Franceschi (1996) calibrated regression equations for estimating living stature from long bone lengths on a sample of European Neolithic skeletons (33 males and 27 females) by using both least-squares (model I) and major axis (model

II) regression techniques. Stature estimates of the skeletal sample have been made by means of Fully's anatomical method, a procedure based on the sum of all osseous components of height, providing the best approximations to the actual stature. The calculated equations have been tested, along with those generally used to predict stature of earlier European remains on a small, well-preserved sample including late upper Paleolithic, Mesolithic, and Neolithic skeletons. The results indicated that the model II equations were particularly useful when very short or very tall individuals are involved and, at the same time, were among the best predictors of stature in less extreme conditions.

Jasuja *et al.* (1997) examined the variations in step length while walking fast, various statistical formulae for stature estimation and the error in stature estimation. The study was based on the measurements of step length in 'normal' and timed fast paced walking, and stature of 198 adult male Jat Sikhs ranging in age from 18 to 58 years collected at random from nearby villages of the district of Patiala in Punjab state. There existed a positive and significant ($P<0.01$) linear correlation between stature and step length at both paces. Although the formulae for stature estimation differed between normal and fast walking, the range of error remained the same, therefore, the authors conclude that the reliability for estimating stature remains the same.

Loss of height occurs in the elderly. Not only is this height valuable to assess, but it creates difficulty for comparison using equations based on estimates of stature in adult populations which often overlook the loss of height with age. Alternatives, such as the use of arm-span or hip length as surrogates for maximum stature during adulthood, have been proposed. In a study of 247 (130 men and 117 women) adult ethnic Chinese living in Melbourne, Australia, Zhang *et al.* (1998) tested the hypothesis that knee height is independent of age and attempted to devise an equation for the estimation of maximum stature in the elderly group (aged 65 years) of this population. Anthropometric indices, including body weight, stature, arm-span and knee height were measured using standard methods and averaged for use in the analysis. In both men and women, the younger adults were taller and had a greater arm-span than their elderly counterparts; however, there was no difference in knee height or body weight between the two groups. Knee height was not associated with age, while stature and arm-span correlated negatively with age. These findings suggested that knee height provided for a valid estimate of stature during early adulthood than arm-span. Knee-height is independent of age and does not appear to decrease over time, in spite of an expected cohort effect in this population. Arm-span, however, appears to change with a cohort as well as with age. Thus, there is a place in a life-time nutritional assessment of the aged to measure both arm-span as an indicator of cohort status and knee height for an individual's maximum achieved stature.

Long bone length is one of the best-known indicators of human stature. Although the long bone length / height ratio differs in tall and short individuals, no detailed study has investigated whether specific formulae should be used to calculate height in different stature groups (Duyar and Pelin, 2003). Therefore, Duyar and Pelin (2003) proposed a new height estimation method based on tibia length in different stature groups. Body height and tibia length were measured in 121 male subjects aged 18.0 – 34.3 years. Three subgroups were established according to body height (short, medium, or tall), using the 15th and 85th percentiles as critical levels. The general formula and a group-specific regression formula were used to estimate height in each subgroup.

A control group with the same properties as the study group was analyzed in the same manner. Particularly with "short" and "tall" subjects, the difference between true height and the height predicted by the group-specific formulae was smaller than the difference observed when the general formula was used. These discrepancies were statistically significant. According to Duyar and Pelin (2003), when estimating height based on tibia length, the individual's stature category should be taken into consideration, and group-specific formulae should be used for short and tall subjects.

1.1.6 OSTEOMETRIC STUDIES ON SOUTH AFRICAN POPULATIONS

Many studies have been performed which described the cranial and postcranial skeleton of South Africans. Intertribal variations as well as differences with other populations have been demonstrated.

A South African case, referred to the Wolkersdorfer case, was reported by Gordon and Drennan in 1948. It necessitated identification of burnt and fragmentary remains. Only the proximal ends of a humerus and a femur were recovered, and estimates had to be made of the length of the whole bones before an estimate of stature could be attempted. For the humerus it was 'that the distance between the head and the lower limit of the deltoid impression usually amounts to about 52% of the total length of the bone', and for the femur ' that the length from the top of the greater trochanter to the nutrient foramen, although variable, usually amounts to about 34% of the total length of the bone.' For neither bone were any details given of the variability of the proportions alluded to.

Washburn (1949) compared South African Black pelves with those of the San and American Blacks and Whites.

Keen (1953) attempted to re-examine the theoretical basis of the methods described by Gordon and Drennan (1948). The author examined 100 random femora and 100 humeri. Three of the femora had no nutrient foramen, and one had a foramen near the distal end of the bone. Of the remaining 96, 25 had 2 nutrient foramina and one had 3. Taking the proximal foramen in those bones which had more than one foramen, the mean proportion as described by Gordon and Drennan (1948) was 35.1%, with a standard deviation of 4.2%. A simple calculation showed that even if the estimation of stature from the length of a femur were reliable, the uncertainty produced by the variability of proportion involved a standard error of the estimate of stature of about 10 cm., and would be useless for any identification purposes. Keen (1953) stated that no reliance can be placed on the position of a nutrient foramen in reconstructing a femur from a proximal fragment.

In the case of 100 humeri; measured in the recommended way, the mean proportion was 52.3% with a standard deviation of 2.1%. In conclusion, Keen (1953) explained that in the Wolkersdorfer case the close agreement between the statures estimated from the fragmentary femur and humerus was fortuitous, and the agreement of each with the known height of the deceased equally so.

De Villiers (1968a, 1968b) studied in great detail the skull Of the South African Black. She stated that "For practical craniological purposes, the tribal series may be regarded as samples of a single South African Negro population" (De Villiers, 1968a). De Beer Kaufman (1974) discussed intertribal variation on the basis of the number of presacral vertebrae in the South African Black. Gaherty (1970, 1973) and Lundy (1986) addressed metrical and morphological intertribal variation in the postcranial skeleton of the South African Black. The results of Lundy's study on the postcranial skeleton confirmed that the South African Black could not be arranged into tribal subdivisions based upon skeletal characteristics. With this conclusion, Lundy (1986) reconfirmed the validity of De Villier's conclusion which was made earlier based on the cranial skeleton.

Lundy (1983) presented regression equations for estimating living stature from long limb bones in the South African Negro. The study was based upon 177 male and 125 female South African Blacks between the ages of 18 and 65 years, from the Raymond A. Dart collection of Human Skeletons housed in the Anatomy Department of the University of the Witwatersrand, Johannesburg. Living stature for the sample were not known, nor were cadaver stature available for the entire sample. In view of this, the mathematical method of regressing long-bone length against living stature or cadaver length could not be utilized. The procedure employed was to calculate the skeletal heights for each individual, according to Fully's (1956) anatomical method. This method entails measuring the basi-bregmatic height of the skull as described by Hrdlicka (1947), the height of each vertebra from C1 to S1, the bicondylar length of the femur as described by Hrdlicka (1947), the length of the tibia without the spines (the bicondylar length of Hrdlicka (1947)), and the articulated height of the talus and calcaneus (Fully, 1956). The maximum anterior height of each vertebra was taken with sliding calipers. In the cases of C2, the measurement was taken from the most superior point on the odontoid process to the inferior margin of the anterior portion of the corpus, and thus included the height of C1 in the measurement. The talus and calcaneus were articulated and measured on a mandible board. These measurements were then added together to obtain the individual's skeletal height.

In addition to the above measurements the maximum lengths of the femur, fibula, ulna, radius, and humerus were taken as described by Hrdlicka (1947). Although these measurements were not included in the determination of skeletal heights, regression equations were derived for each. Once the skeletal heights were calculated the length of the individual long bones, long bones in combination, and the length of the lumbar segment of the spinal column were regressed against skeletal height. Males and females were treated separately. Once a skeletal height was calculated for an individual by means of the equations presented in the study, a correction factor for the soft tissues put forth by Fully (1956) was added to the result. For skeletal heights of 153.5 cm or less, 10.0 cm was added to obtain the estimated living stature. For skeletal heights from 153.6 cm to 165.4 cm, 10.5 cm was added, and for skeletal heights of 165.5 cm and above, 11.5 cm was added to obtain the estimated living stature. To account for the effects of ageing, Trotter and Gleser's

(1952) correction factor was used. For individuals over the age of 30 years, 0.06 cm was subtracted for every year over the age of 30 years. To determine how the equations presented in the study compare with those derived from American Black samples in order to estimate living stature in the South African Black, the mean long-bone lengths for South African Black males were used in both sets of equations. The estimated statures using Trotter and Gleser's (1952) formulae were greater than when the statures were estimated using the equations derived from the South African Black sample. According to Lundy (1983) these equations seem to be more accurate in estimating living stature in the South African Black than those derived for the American Black.

In the course of using Lundy's (1983) equations to estimate stature in a number of Pleistocene fossil hominids, Lundy and Feldesman (1987) discovered that the computer program Lundy (1983) used to compute the regression equations handled missing values in a manner different from what he had expected. Consequently, five cases were admitted to the earlier analysis that clearly should not have been allowed. Their inclusion deflated the correlation, inflated the standard error of the estimates, and yielded poorer fits the data actually warranted. By eliminating these cases, Lundy and Feldesman (1987) were able to derive equations that better reflected the data and enabled better stature estimates for the South African Black. The study was based upon 175 male and 122 female South African Blacks from the Raymond Dart Collection at the University of Witwatersrand, Johannesburg. They eliminated any specimen that did not have the complete suite of skeletal elements needed to compute skeletal height using Fully's (1956) protocol. This reduced Lundy's (1983) original sample by 2 males and 3 females. The earlier inclusion of these specimens resulted in abnormally low skeletal heights, thereby needlessly and erroneously reducing the goodness of fit between the predictor variables and stature. Prior to regression analysis, the authors carefully screened all variables across the sample. They found no instances where values lay outside the mean ± 3 standard deviations. Summary statistics in both male and female samples indicated that the data were distributed normally. They then computed bivariate regression equations between skeletal height and physiological length of the femur, physiological length of the tibia, fibula length, ulna length, radius length, humerus length, lumbar spine length, lumbar spine + femur length + tibia length, femur length + tibia length, and lumbar length + femur length for both male and female samples. The resulting regression equations showed significantly higher correlations and lower standard errors than the values previously published (Lundy, 1983). The femur was the best single bone to use for estimating stature in both males and females, although in the male the tibia was nearly as efficacious. Overall, the combined length of femur + tibia + lumbar vertebral segment represented the best composite predictor of stature. While this conclusion did not differ from that which Lundy (1983) reported earlier, both the strength of correlation and the resultant equations differed markedly. The authors warned researchers of the inadvisability of using these or any other set of stature – predicting equations on a population not demonstrably related to the original population from which the equations were derived.

Steyn and Iscan (1997) used osteometric data from the femora and tibiae of white individuals, to develop standards to determine sex in South African whites. The skeletal remains used for the study were obtained from the collections at the medical schools of the University of Witwatersrand (Dart Collection) and the University of Pretoria. A total of 106 individuals (64 from Dart, 42 from Pretoria; 56 males, 50 females) were measured. The mean age was 66.3 years (ranging from 38-91) for the males and 66.9 years (45-89) for females. A total of six femoral and seven tibial measurements were taken, using standard methods. Femoral measurements were: maximum femoral length, head diameter, circumference at the midshaft, anteroposterior diameter of the midshaft, transverse diameter of the midshaft, and distal breadth. Tibial measurements were: physiological length, proximal epiphyseal breadth, anteroposterior diameter of the midshaft, transverse diameter of the midshaft, circumference of the shaft at the level of the nutrient foramen, minimum circumference, and distal epiphyseal breadth. The analysis of variance was applied to measure the variation within and between groups, then the stepwise discriminant function procedure was used to determine the relative contribution of each variable. The femoral and tibial data were analyzed separately. Variables thus selected were then subjected to a direct discriminant analysis to calculate specific discriminant function formulae for some of the parameters, which can be used on fragmentary remains. Comparative statistics demonstrated that all dimensions were larger in males than females, with the males generally showing the largest variation (significant at $p<0.01$). Results of the stepwise discriminant function for the femur, tibia, and femur and tibia combined were presented. Of the six measurements entered for the femur, only three were selected by the stepwise discriminant analysis in the following order: distal breadth, head diameter, and transverse diameter. For the tibia the distal epiphyseal breadth, the proximal breadth, anteroposterior diameter, circumference and transverse diameter were selected by the stepwise discriminant function in that order. In the case of the test for the combination of the femur and tibia, seven measurements were selected with the femur distal breadth coming out first. Formulae were developed for a number of combinations of measurements, which can be used to determine sex on fragmentary remains. Average accuracies ranged from 86% to 91%, with female accuracies slightly higher than those of the males. The combined method for tibia and femur provided the best result. The use of the distal breadth of femur alone, however, came out nearly as good as the combined use of the femur and tibia. A 98% accuracy was obtained for females when the femur and tibia were used in combination. The results of the study compared well with others. Iscan & Miller-Shaivitz (1986) found that the femur and tibia were almost equally dimorphic in American whites, with the tibia having a slight advantage over the femur. The same was true for Steyn and Ican's (1997) study. According to Steyn and Iscan (1997) as well as Ican and Ding (1995), the distal breadth was the most dimorphic, while in the American whites and blacks (1986) the femoral head was the best. The study also agreed with the finding that width and circumference dimensions add more to the differences between the sexes than do length measurements.

Steyn and Iscan (1999) studied sexual dimorphism in the crania and mandibles of South African Whites to establish population specific standards for sex determination from the skull. Dimensions from the complete cranium provided the best accuracy. Diagnostic accuracy, however, was lower than that obtained from the South African femur and tibia.

Asala (2001) conducted a study to establish the standard numerical values of the identification in South African whites and blacks. A total of 520 femora of white (160 males and 100 females) and black (160 males and 100 females) South Africans were obtained from the Raymond Dart Skeletal Collection in the Department of Anatomical Sciences, the University of the Witwatersrand, Johannesburg, South Africa. The vertical and transverse diameters of the heads of the femora were measured. Identification and demarking points were derived from the values of these diameters. The head diameter identification point and demarking point were found to be sexually dimorphic in both white and black South Africans. The mean head diameter of the male femur was significantly greater than the mean head diameter of the female femur in both population groups (significant at p<0.001).

1.2 MOTIVATION FOR THE STUDY

Race, heredity, climate and nutritional status of a population are known to affect length of long bones and stature. On the basis of this, population biases, and also increases in stature with advancing generations, it was opined that different regression equations, multiplication factors and conversion tables may be required to calculate stature from whole long bones or fragments of long bones for different races, ages and sexes.

The formulae for stature estimation from long bones on various population groups definitely showed a different value for the two sexes (Trotter and Gleser, 1952; Steele and Mckern, 1969; Kate and Mujumdar, 1976; Olivier *et al.*, 1978; Lundy, 1983; Lundy, 1987; Simmons *et al.*, 1990; Holland, 1992; Prasad *et al.*, 1996; Munoz *et al.*, 2001). Kate and Mujumbar (1976) demonstrated that their formulae obtained for Indian bones showed different values for the two sexes and they were also significantly different from Pearson's formulae, derived from English bones commonly used in India for forensic opinions. The technique used by subsequent workers for measuring long bones varies, thus rendering their results incomparable.

In addition, Stevenson (1929), Trotter and Gleser (1952), Boyd and Trevor (1953), Keen (1953), Comas (1960), and Holland (1992) acknowledged the necessity for establishing differentials for each human group studied and concluded from a very comprehensive study. The comparative formulae worked out for various people show that each nationality tends to differ in their proportion as regards stature and long bone length. Furthermore a detailed anthropometric study of the femur revealed a racial variation in whites and blacks and also regional variation.

Stevenson (1929) showed that it is a failure to apply the formulae of one race to give satisfactory prediction results for the second. He emphasized the need of additional data in the form of similar series of regression formulae based on comparable data from specific races.

Racial characteristics of the skeletal system have been well documented. There is plentiful evidence that populations are metrically distinct even within a race group. These population differences have been reported over a range of population groups (El-Najjar and McWilliams, 1978; Hunger and Leopold, 1978; Stewart, 1979;

Krogman and Iscan, 1986; Gill and Thine, 1990). Moreover, temporal differences have been demonstrated, even in relatively recent populations (Borgognini – Tarli and Repetto, 1986; Loth, 1990; Jantz, 1992; Meadows and Jantz, 1995).

Thus, the development of population-specific formulae from documented, contemporary skeletons is necessary.

Estimation of stature from a single extremity bone is a common forensic practice and many regression equations are presented by various workers. However, forensic anthropologists are often confronted with fragmentary remains while the estimation of stature by conventional formulae is dependent upon whole limb bones.

The estimation of living stature from long bones is based upon the principle that the various long limb bones correlate positively with stature. Since, this is true, the parts of each individual long bone should also be related to stature even though they may not correlate as highly as the length of the whole bone. However, since skeletal remains are often fragmentary, the equations generated based on the smaller segments will offer a good opportunity for the estimation of stature.

It is worth having regression equations for bone lengths or stature by applying smaller segments and small bone markers which easily may be available for analysis. If one presents data and provides equations for estimation of stature from small fragments of bone, any recovered section might be used to estimate stature.

Only few previous studies have been done which attempted to offer easily applicable and systematic technique of estimating stature and bone length from small fragments of the femur (Steele & McKern, 1969; Steele, 1970; Simmons *et al.*, 1990; Prasad *et al.*, 1996). These studies were done on samples of specific population groups and the validity of those models was not experimented on different populations.

In South Africa, high numbers of unidentified bodies are discovered each year. Forensic anthropologists in the country are a rarity, and preciously few cases are ever examined by a skilled skeletal biologist (Steyn *et al.*, 1997; Steyn and Iscan, 1997). It is therefore important that standards for skeletal identification for South African populations should be developed, and that these should be easy to apply, so that medical examiners in all parts of the country can use them.

Several forensic anthropological researches have been done in South Africa. Some aspects of the cranial and post-cranial morphology of the South African populations have been described by the works of Shaw (1931), Gordon and Drennan (1948), Washburn (1949), Keen (1953), Jacobson (1967), De Villiers (1968a; 1968b), De Beer Kaufman (1974), Gaherty (1970, 1973), Lundy (1983, 1984, 1986, 1987), Kieser and Groeneveld (1986), Henneberg and Van Den Berg (1990), Kieser *et al.* (1992), Aulsebrook *et al.* (1995, 1996), Steyn and Iscan (1997,1998, 1999), Oettlé and Steyn (2000), and Asala (2001). Yet, many forensic osteometric techniques based on other populations are still in use (Steyn and Iscan, 1999). To date, any attempt has hardly been made to develop formulae for estimating femur length and living stature in South African populations from fragments of the femur. Therefore, this study attempts to develop standards to estimate femur length and living stature in South African populations using clearly defined and easily applicable femoral segments.

In order to apply previously developed equations for femur length or stature estimation to South African Population groups, their validity needs to be determined. If they are found to be unreliable, the new models developed by this study using skeletal material of South African population groups should be of use to archeologists, physical anthropologists, and forensic specialists working in South Africa.

The length of femur thus calculated from its fragments can be used to estimate the stature of the individual by using available regression equations, tables and multiplication factors. The femur is used in this study because, in addition to its high correlation with stature, it is one of the bones in which its parts are most frequently recovered from airplane crash sites and other accidents. It is a large, durable bone protected by both large amount of soft tissue and the seat and harness mechanisms of the aircraft.

1.3 OBJECTIVES OF THE STUDY

1.3.1 GENERAL OBJECTIVE

♣ To estimate the length of femur using fragment measurements on its proximal and distal ends.

1.3.2 SPECIFIC OBJECTIVES

♣ To evaluate the correlation between length of femur and its segments.

♣ To examine the intercorrelations existing among the various fragment measurements.

♣ To develop simple linear regression equations for estimation of femur length from its fragments for each sex, race and the total study sample.

♣ To develop multiple linear regression equations for each race and sex to estimate femur length by a combination of two or more segments with the highest predictive efficiency.

♣ To test differences between races and sexes regarding femur length and other segment measurements.

♣ To compare the results of this study with those of other studies.

♣ To evaluate the validity of previously developed models to the present study population.

CHAPTER 2: MATERIALS AND METHODS

2.1 DEFINITION OF TERMS

Femur: is the single long bone of the thigh. It has a body (Shaft), a head, and a lower end formed by two condyles (Hall – Craggs, 1985; Moore, 1992).

Summit of the Head of Femur : The most medial (farthest) point on the head of femur, just superior to fovea capitis (Simmons *et al.*, 1990; Parsad *et al.*, 1996).

Intertrochanteric Line: a broad, rough line which runs inferomedially from the greater trochanter to the lesser trochanter of the femur (Moore, 1992; Basmajian and Slonecker, 1989). Fig.1.

Axis of the Neck: is a line joining two center points on the anterior surface of the neck of femur (Singh and Bashin, 1989; Prasad *et al.*, 1996; Isaac *et al.*, 1997).

Axis of the Shaft: is a line joining two center points on the anterior surface of the shaft of femur (Singh and Bashin, 1989; Prasad *et al.*, 1996; Isaac *et al.*, 1997).

Intertrochanteric Apical Axis: is the extension of the axis of the neck to the summit of the head (Isaac *et al.*, 1997).

Maximum Femoral Length (FL): is the straight distance between the most superior point of the head of femur to the most inferior point on the lateral/medial condyle. It is measured using an osteometric board (Hrdlicka, 1952; Montagu, 1960; Walensky, 1965; Steele and McKern, 1969; Yoshioka *et al.*, 1987).

Neck-Shaft Angle (NSA): is the angle between axis of the neck and axis of the shaft. It is measured using a goniometer (Singh and Bashin, 1989; Simmons *et al.*, 1997). Fig.1.

Neck Length (NL): is the distance between the base of the head and the point of intersection of the intertrochanteric apical axis with the intertrochanteric line. It is measured using a sliding caliper (Isaac *et al.*, 1997). Fig.1.

Intertrochanteric Apical Axis Length (ITAAL): is the distance between the summit of the head and the point of intersection of the intertrochanteric apical axis with the intertrochanteric line. It is measured using a sliding caliper (Isaac *et al.*, 1997). Fig.1.

Maximum Vertical Diameter of head of femur (VDH): is taken at right angle to axis of the neck and represents the straight distance between the most superior and most inferior points of the head. It is measured with a sliding caliper (Javadekar, 1961; Kate, 1964; Singh and Bashin, 1989; Simmons *et al.*, 1990; Prasad *et al.*, 1996; Isaac *et al.*, 1997). Fig.1.

Upper Breadth of Femur (VHA) (Upper epiphyseal length, along the axis of the femoral neck) : is the distance between the farthest (most medial) point on the head (summit of the head) to the terminis of the neck axis on the lateral side of the bone. Its measurement is taken using a sliding caliper (Simmons *et al.*, 1990). Fig.1.

Lateral Condyle Height (LCH): is the projected distance from the most superior to the most inferior point on the lateral condyle. It is measured with a sliding caliper (Simmons *et al.*, 1990). Fig.1.

2.2 STUDY DESIGN

This is a comparative study involving measurement of various parameters on the femur. It compares the parameters between races and sexes within the study sample as well as with other studies.

2.3 STUDY POPULATION AND SAMPLING

The material used in this study consisted of a total of 400 adult, dry femora, devoid of gross pathology from South African Whites and Blacks (200 from each race with 100 males and 100 females). To be included in the sample an individual must have race and sex recorded on the morgue record. The age range of the sample is between 20 and 89 years. The subjects died fairly recently. The sample was obtained from the Raymond A. Dart Collections of Human Skeletons. The collection is housed in the Department of Anatomical Sciences, University of Witwatersrand, Johannesburg. For the purpose of this study, Black South Africans were considered as a homogenous group (DeVilliers, 1968; Lundy, 1986; Oettlé and Steyn, 2000), and no distinction was made between the various groups within the South African Black groups of people. It should, however, be noted that the Black female group consisted of 62 Zulu and 38 from the Sothos. The male group consisted of 92 Zulus, 7 Sothos, and 1 Khoisan.

The South African white population were formed by waves of various European groups, originally from the Netherlands, but later by a variety of settlers from Britain, France and Germany. Smaller additions came from Portuguese and other European groups. Admixture with local groups may also have added to the genetic composition of this population group (Steyn and Iscan, 1997).

2.4 MEASUREMENTS

Maximum length of the femur (FL), neck-shaft angle (NSA), neck length (NL), maximum vertical diameter of the head of femur (VDH), intertrochanteric apical axis length (ITAAL), upper breadth of femur (VHA), and lateral condyle height (LCH) were measured. The landmarks on the proximal and distal aspects of femur are shown in Fig.1. The various segments are defined and measured using well defined anatomical landmarks and standard techniques.

The neck-shaft angle (NSA) is measured to the nearest degree. All the other measurements are taken to the nearest millimeter. All measurements were taken by the investigator. Practice measurements were made on fifty specimens before any data were recorded. This provided for an acquaintance with the skeletal material, as well as facilitated the handling and use of instruments. In general, the methods used were those adopted by Stewart (1962).

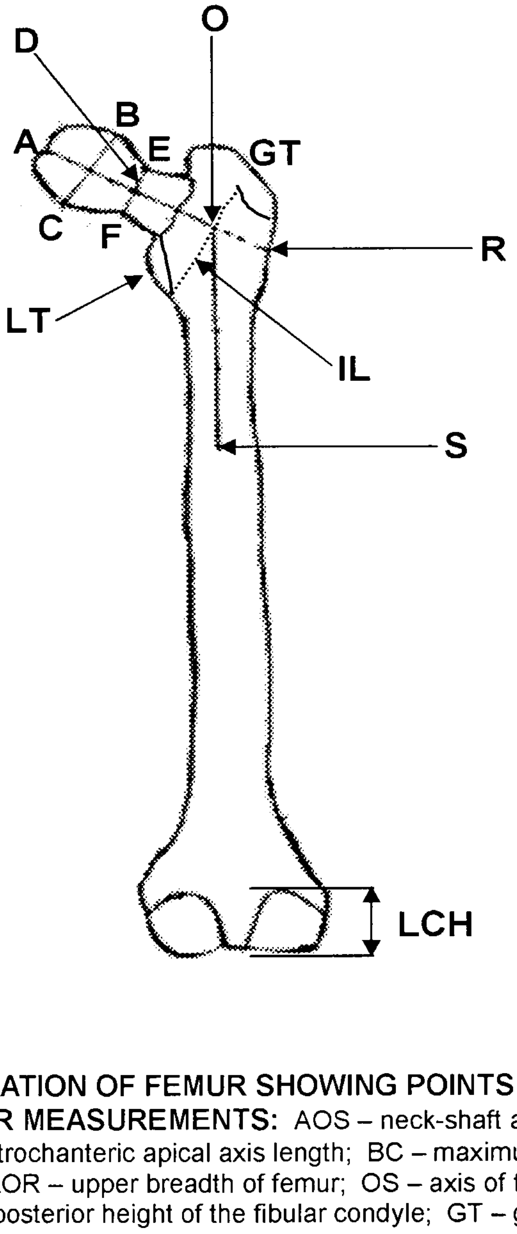


FIG. 1 ILLUSTRATION OF FEMUR SHOWING POINTS FOR MARKER MEASUREMENTS: AOS – neck-shaft angle; DO – neck length; AO – intertrochanteric apical axis length; BC – maximum vertical diameter of the femur head; AOR – upper breadth of femur; OS – axis of the shaft; EF – base of the head; LCH – posterior height of the fibular condyle; GT – greater trochanter; LT – lesser trochanter; IL – intertrochanteric line

Maximum femur length was measured following the techniques of Hrdlicka (1962), Montagu (1960), Stewart (1962), and Walensky (1965). Maximum femur length was measured from the medial condyle to the head. The bone is placed on its posterior surface on the osteometric board. The greatest length is measured from the medial condyle, which rests against the vertical wall of the osteometric board, to the extreme point of the head of the femur. A movable block at right angles to the graduated rule of the board is applied to the most prominent point of the head. The measurement of the maximum length is read from the graduated rule. The average of a pair was utilized in the statistics because of greater reliability of an average. Further more, there is no significant difference in length between the bones of the two sides and when the bone of only one side is available an adjustment in an equation based on the average is not necessary (Trotter and Gleser, 1952; Genoves, 1967; Mclaughlin and Bruce, 1985).

Two center points on each of the neck and shaft of femur were marked using a pencil. A line joining the two center points on the neck of femur was drawn using a pencil and formed the axis of the neck. The two center points on the shaft were also joined by a line using a pencil to construct axis of the shaft. When extending the neck axis to the summit of the head upwards and beyond the intertrochanteric line downwards, two important lines are constructed. The entire line (from the summit to the lateral end of the neck axis just below the greater trochanter) forms the subtrochanteric apical axis (Isaac *et al.*, 1997).

The other axis is the intertrochanteric apical axis, which is the line between the summit of the head and the intersection point of the neck axis with the intertrochanteric line. Therefore, the various segments on the proximal aspects of femur were defined and measured based on these axes. For instance, the NSA is the angle formed between axis of the neck and axis of the shaft. It is measured using a goniometer. Likewise, all the other variables are measured using these well defined axes. The lateral condyle height (LCH), of course, is defined and measured using a well identified anatomical landmark on the lower end of the femur, i.e., the lateral or fibular condyle.

To minimize intraobserver variation, all variables were measured twice and the average was recorded.

2.5 DATA MANAGEMENT AND ANALYSIS

The raw data were entered into a computer by the researcher and basic statistics, t-test procedure, correlation analysis, and regression analysis were performed. Data were also analyzed by the department of Biostatistics, University of the Free State, Bloemfontein using various procedures of a PC version of SAS (1990). The student's t-test was used to calculate the significant differences of the means between the sexes and races within the study sample as well as with previous studies. The critical value was placed at the 0.05 level for a two tailed test.

Correlation coefficients were calculated between femoral length and the other segments. Further more, intercorrelation matrices among the various segments are presented.

Correlation analysis examines as to whether there is a relationship between two variables or not. In other words, it shows if one variable tends to be correspondingly high or low. A numerical measure of the observed association between two variables is the correlation coefficient 'r'. The correlation coefficient can be used in the initial examination of a data set to identify relationships which deserve further study. The correlation analysis in the present study clearly determines the relationship existing between femoral length and the other six fragment measurements. Furthermore, the correlations among the six fragment measurements are also presented in order to show the interrelation existing among each other. Once the correlation coefficients are established, it is generally more useful to think of linking two variables via a regression equation. From a regression analysis one can see very directly how changes in one predictor variable are associated with changes in the other outcome variable.

Length of femur was regressed on the different segments studied and linear regression equations based on the least squares method were developed. Therefore, linear regression models of the form $Y = a + bx$ were derived for each group, where 'Y' is the dependent or outcome variable (femoral length), 'b' is the slope or coefficient of regression, 'x' is the explanatory or predictor variable (each segment), and 'a' is the intercept of the equation which is a constant.

In addition, the best fitting multiple linear regression equations using two or more segments in combination were derived for each race and sex. Stepwise selection procedure was used to select the combination of variables with the best predictive efficiency for estimation of femur length (with $p<0.15$ to enter and $p>0.15$ to remove). Based on this, multiple linear regression equations of the form $Y = a + b_1x_1 + b_2 x_2 + b_3 x_3 \ldots + b_n x_n$ were derived for each race and sex.

For each equation the coefficient of determination (r^2) and standard error of the estimate (S.E.E.) are indicated. The coefficient of determination (r^2) shows the percent of variation that can be explained by the regression equation. The ratio of the explained variation to the total variation is a measure of how good the regression line is. If the regression line passed through every point on the scatter plot exactly, it would be able to explain all the variation. The further the line is from the points, the less it is able to explain. The coefficient of determination indicates how much of the total variation in the dependent variable can be accounted for by the regression function. A coefficient of determination (r^2) 0.70 implies that 70% of the variation in the dependent variable is accounted for by the regression function.

Standard error of the estimate (S.E.E.) is a measure of the accuracy of predictions made with the regression line.

In the stepwise selection procedure predictor variables are added one by one to the model, and the *F* statistic for a variable to be added to the model must be significant at the 0.15 level. After a variable is added, however, the stepwise method looks at all the variables already included in the model and deletes any variable that does not produce an *F* statistic significant at the 0.15 level. Only after this check is made and the necessary deletions accomplished can another variable be added to the model. The stepwise process ends when none of the variables outside the model has an *F* statistic significant at the 0.15

level and every variable in the model is significant at the 0.15 level, or when the variable to be added to the model is the one just deleted from it.

The R – square selection method was also employed to calculate the R – square of all possible prediction models using a single variable or any combination of them (Appendix-A). Using this, it is possible for one to select the variable (s) of choice if prediction is to be made with only one variable or two or more variables. The R – square selection method finds subsets of variables that best predict a dependent variable by linear regression in the given sample. One can specify the largest and smallest number of independent variables to appear in a subset and the number of subsets of each size to be selected. The R – square selection method can efficiently perform all possible subset regressions and display the models in decreasing order of R^2 magnitude within each subset size.

In addition, the adjusted R-square selection method (Appendix-B) was employed to calculate the adjusted R-square of a single or any combination of variable(s). Hence, the adjusted R-squares are presented in a descending order and the combinations of variables in the model resulting in a particular adjusted R-square value are indicated. This method is similar to the R-square selection method, except that the adjusted R-square statistic is used as the criterion for selecting models, and the method finds the models with the highest adjusted R^2 within the range of sizes.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 DESCRIPTIVE STATISTICS

The age, race and sex of subjects contributing to this study are presented in Table 1. Age is that recorded at the time of death. Age for one subject in the Black males is not available in the record. The distribution of subjects is shown in Fig. 2. The Mean age for the White males, Black males, White females and Black females is 57.14, 42.13, 62.35, and 37.74, respectively (Table 2). The mean age of the White group is considerably older than the Black group and the spread is wider extending into the later decades.

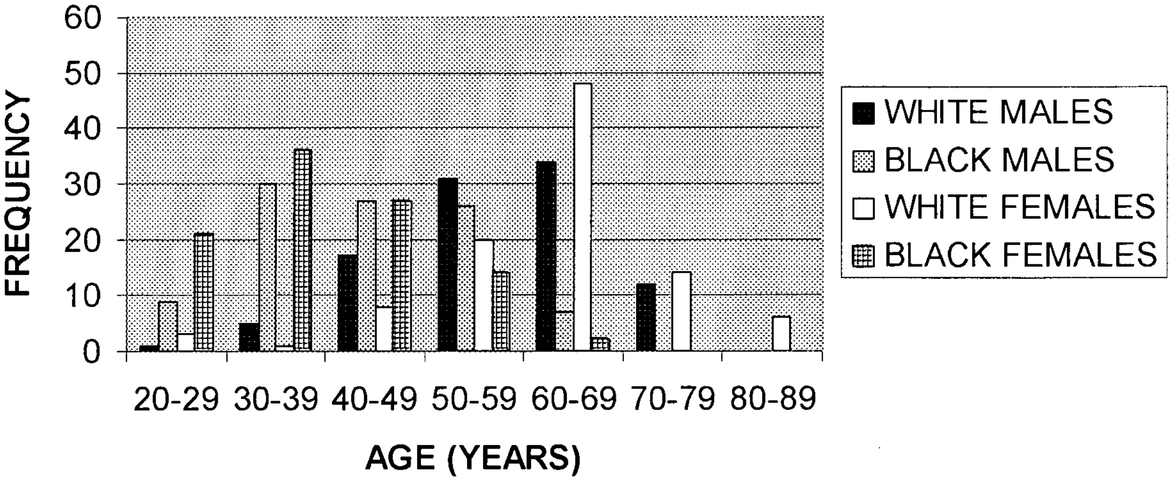
TABLE 1: DISTRIBUTION OF SUBJECTS ACCORDING TO AGE (YRS), RACE AND SEX

AGE	WHITE MALE (n = 100)	BLACK MALE (n = 100)	WHITE FEMALE (n = 100)	BLACK FEMALE (n = 100)
20 – 29	1	9	3	21
30 – 39	5	30	1	36
40 – 49	17	27	8	27
50 – 59	31	26	20	14
60 – 69	34	7	48	2
70 – 79	12		14	–
80 – 89	–		6	–
TOTAL	100	99	100	100

TABLE 2: MEAN (WITH STANDARD ERROR), STANDARD DEVIATION AND RANGE OF AGE (YRS), ACCORDING TO RACE AND SEX

		RANGE	MEAN	S.D.	MEDIAN
White	M (n = 100)	28 – 73	57.14	10.50	58
	F (n = 100)	21 – 89	62.35	11.72	64
Black	M (n = 100)	22–65	42.13	10.42	40
	F (n = 100)	20 – 60	37.74	9.53	38

FIG. 2 DISTRIBUTION OF SUBJECTS ACCORDING TO AGE (YEARS), RACE AND SEX



Tables 3 through Table 7 summarize the descriptive statistics of all the variables for White males, Black males, White females, Black females, and the totals respectively.

Each table includes the mean, standard deviation, median, minimum and maximum values for each variable. The neck-shaft angle is measured in degrees while all the rest are measured in millimeters. Accordingly the mean femoral length for South African White males, Black males, White females, and Black females is 467.1 mm, 449.0 mm, 431.5 mm, and 426.1 mm, respectively. White males have the highest mean neck-shaft angle and White females have the lowest. Mean neck length is the highest in White males (36.7 mm) and the lowest in the Black females (26.7 mm). The highest mean intertrochanteric apical axis length is seen in the White males and the lowest in the Black females. Mean vertical diameter of the femoral head is also highest in the White males and lowest in the Black females. Mean upper breadth of the femur is highest in the White males and lowest in the Black females. Once more the highest mean lateral condyle height is observed in the White males and the lowest in the Black females.

TABLE 3: DESCRIPTIVE STATISTICS OF ALL THE VARIABLES FOR SOUTH AFRICAN WHITE MALES

VARIABLE	N	MEAN	STANDARD DEVIATION	MEDIAN	MINIMUM	MAXIMUM
FL mm	100	467.1	25.94	469.5	418.0	539.0
NSA°	100	124.1	6.65	125.0	105.0	139.0
NL mm	100	36.7	4.42	37.0	25.0	48.0
ITAAL mm	100	70.8	4.67	71.0	60.0	82.0
VDH mm	100	48.5	2.57	49.0	42.0	55.0
VHA mm	100	103.0	6.69	103.0	84.0	118.0
LCH mm	100	42.4	2.95	42.0	36.0	50.0

FL = Femoral length
NSA = Neck-shaft angle
NL = Neck length
ITAAL = Intertrochanteric apical axis length
VDH = Maximum vertical diameter of femoral head
VHA = Upper breadth of the femur
LCH = Lateral condyle height

TABLE 4 DESCIPTIVE STATISTICS OF ALL THE VARIABLES FOR SOUTH AFRICAN BLACK MALES

VARIABLE	N	MEAN	S.D.	MEDIAN	MINIMUM	MAXIMUM
FL mm	100	449.0	26.45	451.0	397.0	515.0
NSA°	100	121.9	5.14	122.0	105.0	136.0
NL mm	100	32.2	4.83	32.0	21.0	46.0
ITAAL mm	100	63.1	5.27	62.0	52.0	78.0
VDH mm	100	45.0	2.82	45.0	37.0	51.0
VHA mm	100	95.7	6.62	96.0	80.0	112.0
LCH mm	100	39.1	3.20	39.0	31.0	45.0

FL = Femoral length
NSA = Neck-shaft angle
NL = Neck length
ITAAL = Intertrochanteric apical axis length
VDH = Maximum vertical diameter of femoral head
VHA = Upper breadth of the femur
LCH = Lateral condyle height
S.D. = Standard Deviation

As can be seen from Tables 3 through 6, the mean femoral length is highest in White males and lowest in Black females. If we list the groups in descending order based on the mean femoral length, we find White males, Black males, White females, and Black females in that order. It is interesting that mean measurements of all the other variables follow quite a uniform pattern like that of the femur length. The only exception which disrupts this pattern is the mean neck-shaft angle which is smaller for the White females (119.8^{O}) than the Black females (121.9^{O}). With all the other variables, the highest mean is found in White males and the lowest in the Black females. Black males and White females consistently take intermediate positions the former of course exceeding the latter.

Table 7 shows the range, mean, median, standard deviation, minimum, and maximum values of femoral length (FL), neck-shaft angle (NSA), neck length (NL), intertrochanteric apical axis length (ITAAL), vertical diameter of the femoral head (VDH), upper breadth of femur (VHA), and lateral condyle height (LCH) for the total sample of this study. The Table includes the values the dimensions without consideration of race and sex.

TABLE 5: DESCRIPTIVE STATISTICS OF ALL THE VARIABLES FOR SOUTH AFRICAN WHITE FEMALES

VARIABLE	N	MEAN	S.D.	MEDIAN	MINIMUM	MAXIMUM
FL mm	100	431.5	27.38	435.0	318.0	492.0
NSA°	100	119.8	7.49	120.0	105.0	138.0
NL mm	100	30.6	4.10	31.0	22.0	44.0
ITAAL mm	100	62.6	5.05	61.5	53.0	80.0
VDH mm	100	42.1	2.87	42.0	33.0	52.0
VHA mm	100	91.9	8.09	91.0	77.0	117.0
LCH mm	100	37.0	2.99	37.0	31.0	46.0

FL = Femoral length
NSA = Neck-shaft angle
NL = Neck length
ITAAL = Intertrochanteric apical axis length
VDH = Maximum vertical diameter of femoral head
VHA = Upper breadth of the femur
LCH = Lateral condyle height
S.D. = Standard deviation

TABLE 6: DESCRIPTIVE STATISTICS OF ALL THE VARIABLES FOR SOUTH AFRICAN BLACK FEMALES

VARIABLE	N	MEAN	S.D.	MEDIAN	MINIMUM	MAXIMUM
FL mm	100	426.1	21.31	425.5	372.0	483.0
NSA°	100	121.5	5.12	121.0	111.0	140.0
NL mm	100	26.7	4.09	27.0	18.0	38.0
ITAAL mm	100	55.8	4.29	55.0	42.0	68.0
VDH mm	100	40.5	2.26	40.0	35.0	46.0
VHA mm	100	85.5	5.09	85.0	74.0	100.0
LCH mm	100	34.1	2.46	34.0	30.0	41.0

FL = Femoral length
NSA = Neck-shaft angle
NL = Neck length
ITAAL = Intertrochanteric apical axis length
VDH = Maximum vertical diameter of femoral head
VHA = Upper breadth of the femur
LCH = Lateral condyle height
S.D. = Standard deviation

TABLE 7 DESCRIPTIVE STATISTICS OF ALL THE VARIABLES FOR THE TOTAL STUDY SAMPLE WITHOUT CONSIDERING RACE AND SEX

VARIABLE	N	MEAN	S.D.	MEDIAN	MINIMUM	MAXIMUM
FL mm	100	443.4	29.99	441.0	318.0	539.0
NSA°	100	121.8	6.33	122.0	105.0	140.0
NL mm	100	31.5	5.63	31.0	18.0	48.0
ITAAL mm	100	63.1	7.18	62.0	42.0	82.0
VDH mm	100	44.0	4.02	44.0	33.0	55.0
VHA mm	100	94.1	9.28	94.0	74.0	118.0
LCH mm	100	38.1	4.21	38.0	30.0	50.0

3.2 COMPARISON OF DIFFERENT GROUPS WITHIN THE STUDY SAMPLE

Two tailed unpaired t-test was used to calculate the significant difference between two means in each comparison. Table 8 through 11 compare the means and standard deviations of FL, NSA, NL, ITAAL, VDH, VHA, and LCH for the different groups of subjects. Specifically, Table 8 and 9 compare the presence of any significant difference in each variable between two sexes of the same race while Table 10 and 11 compare the difference between Blacks and Whites of the same sex. The p-value and 95% confidence intervals are presented in each case.

TABLE 8: COMPARISON OF THE DIMENSIONS BETWEEN SOUTH AFRICAN WHITE MALES AND FEMALES

DIMENSION	RACE & SEX	N	MEAN	S.D.	95% C.I.	p
FL mm	White male	100	467.1	25.94	(462.0; 472.3)	<0.0001
	White female	100	431.5	27.38	(426.1; 436.9)	
NSA°	White male	100	124.1	6.56	(122.8; 125.4)	<0.0001
	White female	100	119.8	7.49	(118.3; 121.3)	
NL mm	White male	100	36.7	4.42	(35.8; 37.5)	<0.0001
	White female	100	30.6	4.10	(29.8; 31.4)	
ITAAL mm	White male	100	70.8	4.67	(69.9; 71.8)	<0.0001
	White female	100	62.6	5.05	(61.6; 63.6)	
VDH mm	White male	100	48.5	2.57	(48.0; 49.0)	<0.0001
	White female	100	42.1	2.87	(41.6; 42.7)	
VHA mm	White male	100	103.3	6.69	(101.9; 104.6)	<0.0001
	White female	100	91.9	8.09	(90.3; 93.5)	
LCH mm	White male	100	42.4	2.95	(41.8; 43.0)	<0.0001
	White female	100	37.0	2.99	(36.4; 37.6)	

S.D. = Standard Deviation C.I. = Confidence interval

TABLE 9: COMPARISON OF THE DIMENSIONS BETWEEN SOUTH AFRICAN BLACK MALES AND FEMALES

DIMENSION	RACE & SEX	N	MEAN	S.D.	95% C.I.	p
FL mm	Black male	100	449.0	26.45	(443.8; 454.3)	<0.0001
	Black female	100	426.1	21.31	(421.8; 430.3)	
NSA°	Black male	100	121.9	5.14	(120.9; 122.9)	N.S.
	Black female	100	121.5	5.12	(120.5; 122.5)	
NL mm	Black male	100	32.2	4.83	(31.2; 33.1)	<0.0001
	Black female	100	26.7	4.09	(25.9; 27.5)	
ITAAL mm	Black male	100	63.1	5.27	(62.1; 64.2)	<0.0001
	Black female	100	55.8	4.29	(55.0; 56.7)	
VDH mm	Black male	100	45.0	2.82	(44.4; 45.5)	<0.0001
	Black female	100	40.5	2.26	(40.1; 41.0)	
VHA mm	Black male	100	95.7	6.62	(94.4; 97.0)	<0.0001
	Black female	100	85.5	5.09	(84.5; 86.5)	
LCH mm	Black male	100	39.1	3.20	(38.4; 39.7)	<0.0001
	Black female	100	34.1	2.46	(33.6; 34.5)	

S.D. = Standard Deviation
C.I. = Confidence interval
N.S. = Non-significant

3.2.1 COMPARISON OF MALES AND FEMALES OF THE SAME RACE

Table 8 compares the difference in each dimension between White males and females of the present sample. The comparison between Black males and females with respect to the dimensions is also shown in Table 9. The femur is significantly longer in the White males than in the White females (P<0.0001). Similarly Black males have significantly longer femora (P<0.0001) than Black females. The neck-shaft angle is narrower (P<0.0001) in White females than the White males, the means being 119.8^{O} and 124.1^{O}, respectively. However, there is no significant difference in the Neck-Shaft Angle between the males and females of the Black group. The mean NSA for the Black males and females is 121.9^{O} and 121.5^{O}, respectively. Absence of a difference in the NSA between the two sexes is not attributed to sampling error but may be explained by the general trend in the morphological make-up of the given populations which is influenced by several factors: genetics, environment, activity pattern, nutrition, etc. (Klepinger, 2001; Gill, 2001).

Prasad *et al.* (1996) have also published similar results in their study on 171 femora from Southern Indian subjects. According to them, there was no statistically significant difference between males and females of their subjects concerning the neck-shaft angle (NSA). In their study, the mean NSA for males and females was 126.8° and 126°, respectively.

These findings on the South Indian femora agree well with the results of the present study for the Black South African group where there is no significant difference in the NSA between males and females.

All the remaining dimensions (NL, ITAAL, VDH, VHA and LCH) are significantly greater ($P<O.0001$) in males than in females of both population groups. It is a preliminary indicator of the existence of a specific relationship between the measured variables and the length of femur as the femur is significantly longer in males than the females of both population groups. Sexual dimorphism in the dimensions of femur has been reported over a wide range of races world wide (Trotter and Gleser, 1952; Genoves, 1967; Steele and McKern, 1969; Singh and singh, 1974; Black, 1978; DiBennardo and Taylor, 1979; Taylor and DiBennardo, 1982; Lundy, 1983; MacLaughlin and Bruce, 1985; Komatsu, 1986; Yoshioka *et al.,* 1987; Wu, 1989; Simmons *et al.*, 1990; Nwoha, 1991; Iscan and Shihai, 1995; Prasad *et al.*, 1996; Trancho *et al.*, 1997; Steyn and Iscan, 1997; King *et al.*, 1998; Stojanowski and Seidmann, 1999; Mall *et al.*, 2000; DeMendonca, 2000; Munoz *et al.*, 2001; Tahir *et al.*, 2001; Asala., 2001; Šlaus *et al.*, 2003). Hence, based on the results of Table 8 and 9, one can conclude that while deriving formulae for estimation of femoral length from its fragments, the two sexes should be treated separately in each population group. In other words the need for sex-specific formulae is clearly visible.

3.2.2 COMPARISON OF SOUTH AFRICAN WHITES AND BLACKS OF THE SAME SEX

Table 10 presents comparison of South African White males and Black males with respect to the various dimensions. Comparison between South African White females and Black females is presented in Table 11. From Table 10 one can see clearly that the white males and the black males are significantly different (P<O.0001) in the length of femur. The femur is considerably longer in the white males with mean 467.1 mm than in the black males with a mean of 449.0 mm. However, females of the two races do not have a significant difference in the mean femoral length (Table11).

TABLE 10: COMPARISON OF THE DIMENSIONS BETWEEN SOUTH AFRICAN WHITE AND BLACK MALES

DIMENSION	RACE & SEX	N	MEAN	S.D.	95% C.I.	p
FL mm	White male	100	467.1	25.94	(462.0; 472.3)	<0.0001
	Black male	100	449.0	26.45	(443.8; 454.3)	
NSA°	White male	100	124.1	6.56	(122.8; 125.4)	<0.01
	Black male	100	121.9	5.14	(120.9; 122.9)	
NL mm	White male	100	36.7	4.42	(35.8; 37.5)	<0.0001
	Black male	100	32.2	4.83	(31.2; 33.1)	
ITAAL mm	White male	100	70.8	4.67	(69.9; 71.8)	<0.0001
	Black male	100	63.1	5.27	(62.1; 64.2)	
VDH mm	White male	100	48.5	2.57	(48.0; 49.0)	<0.0001
	Black male	100	45.0	2.82	(44.4; 45.5)	
VHA mm	White male	100	103.3	6.69	(101.9; 104.6)	<0.0001
	Black male	100	95.7	6.62	(94.4; 97.0)	
LCH mm	White male	100	42.4	2.95	(41.8; 43.0)	<0.0001
	Black male	100	39.1	3.20	(38.4; 39.7)	

S.D. = Standard Deviation
C.I. = Confidence interval

TABLE 11: COMPARISON OF THE DIMENSIONS BETWEEN SOUTH AFRICAN WHITE AND BLACK FEMALES

DIMENSION	RACE & SEX	N	MEAN	S.D.	95% C.I.	p
FL mm	White female	100	431.5	27.38	(426.1; 436.9)	N.S.
	Black female	100	426.1	21.31	(421.8; 430.3)	
NSA°	White female	100	119.8	7.49	(118.3; 121.3)	N.S.
	Black female	100	121.5	5.12	(120.5; 122.5)	
NL mm	White female	100	30.6	4.10	(29.8; 31.4)	<0.0001
	Black female	100	26.7	4.09	(25.9; 27.5)	
ITAAL mm	White female	100	62.6	5.05	(61.6; 63.6)	<0.0001
	Black female	100	55.8	4.29	(55.0; 56.7)	
VDH mm	White female	100	42.1	2.87	(41.6; 42.7)	<0.0001
	Black female	100	40.5	2.26	(40.1; 41.0)	
VHA mm	White female	100	91.9	8.09	(90.3; 93.5)	<0.0001
	Black female	100	85.5	5.09	(84.5; 86.5)	
LCH mm	White female	100	37.0	2.99	(36.4; 37.6)	<0.0001
	Black female	100	34.1	2.46	(33.6; 34.5)	

S.D. = Standard Deviation
N.S. = Non-significant
C.I. = Confidence interval

Even though the white females have a relatively longer femur with a mean of 431.5 mm than the black females with a mean of 426.1 mm, the observed difference in the length of femur does not reach to a level of statistical significance at the 5% critical level. According to previous studies the blacks of both sexes in general have longer limb-bones than the white counterparts. Trotter and Gleser (1952) summarized this observation as follows:

"The Negroes of both sexes have significantly longer bones of the free limbs than do the white groups... ". This trend can also be studied easily from Table 12 for the different samples presented there in. In all previous works indicated in the table, blacks of both sexes have longer limb bones including the femur than the white group. This goes in contradiction to the results observed in the present study. It is quite interesting to find here that the opposite holds true. Unlike the other studies mentioned, the whites of both sexes included in this study have longer femora than the black counterparts. Metric differences between South African Whites and Blacks has been demonstrated by Steyn and Iscan, (1999) for the humerus. The authors showed that humeral dimensions are larger in South African Whites than Blacks. This is a typical illustration of population variation. Skeleton development is influenced by a number of factors producing differences in skeletal proportions between different population groups and geographical areas (Muñoz *et al.*, 2001). Theodore Cole (1994) and Christopher Ruff (1994) had shown that aspects of femur morphology could be attributed to biomechanics. Cole (1994) cautions, however, that observed differences could also be due to genetics as well as environment.

Trancho *et al.* (1997) explained that without doubt actual populations are biologically more heterogeneous than prehistoric and historic populations. Similarly, many physical changes may be the result of socioeconomical and nutritional changes.

The findings of this study are of paramount importance in that they demonstrate a clear objective for the need to derive specific formulae for South Africans to estimate stature and bone lengths. In particular the considerable difference in the length of femur observed in the South African blacks of both sexes when compared to those of other studies provides an objective reason not to apply formulae to these groups based on black samples of a different source. The need for population-specific formulae and multiplication factors has been addressed by numerous authors (Stevenson, 1929;Trotter & Gleser, 1952; Keen, 1953; Krogman, 1962; Kate and Mujumdar 1976; Lundy, 1983; Lundy, 1987; Simmons *et al.*, 1990; Prasad *et al.*, 1996; Holland, 1992; Jacobs, 1992; Jantz, 1992; Sciulli *et al.*, 1993; Jason and Taylor, 1995; Meadows and Jantz, 1995; Jantz and Jantz, 1999; Munoz, *et al.*, 2001; Radoinova *et al.*, 2002; Ross and Konigsberg, 2002).

On a similar issue, Keen (1953) stated that various population groups differ sufficiently in their body proportions to make tables or formulae derived from one population group unsatisfactory for use on another population. Stevenson (1929) first showed this when he attempted to use Pearson's formulae on Chinese material. Gleser & Trotter (1952) comparing American Whites and Blacks have clearly shown the necessity of using figures derived from the population under investigation. Kate and Mujumdar (1976) also commented that a detailed anthropometric study of the femur revealed racial variation in Whites and Blacks and also regional variation in the case of the Indian femur. This led to verification of Pearson's formulae as regards its correctness in the case of Indian bone and thus the work was undertaken at places where the correct and reliable record of stature of the body was maintained. In general, there are no universal formulae or tables to be used for any population group as each group differs in the proportion of the length of long bones. Therefore, each population group and sex should be treated separately according to equations derived based on a sample from a uniform population group.

When the neck-shaft angle (NSA) is considered for comparison between the two races, we can see from Table 10 that there is a significant difference ($P<0.01$) between the White males and Black males. The mean NSA for the White males is 124.11° while it is 121.92° for the Black males. On the other hand, the White females and Black females have no statistically significant difference in NSA measurement at the 5% critical level (Table 11). The mean measurement of NSA for White females and Black females is 119.80° and 121.49°, respectively. Table 10 indicates that for all the remaining five segments considered in this study (NL, ITAAL, VDH, VHA, LCH), there is a statistically significant difference ($P<0.0001$) between the White males and the Black males. The mean measurements for these five segments are considerably higher in the White males than the Black males. In a similar fashion, one can see from Table 11 that there is a statistically significant difference ($P<0.0001$) between the White females and Black females for these same five segments (NL, ITAAL, VDH, VHA, LCH). The White females significantly exceed the Black females in the mean measurement of all the five segments. With the exception of the NSA in the females group, all segment measurements are consistent with those observed in the length of femur. Until verified with the appropriate statistical procedures (correlation and regression models), the observed result in the mean length of femur and other segments points toward the assumption of the proportional nature of bone measurements as well as of the human body in general. This remark is set forth following the observation that mean segment measurements tend to be higher when the mean femoral length is longer and they tend to be lower when the mean length of femur is shorter.

3.3 COMPARISON OF THE PRESENT RESULTS WITH OTHER STUDIES

Table 12 compares age and femur length of the present sample with other samples that have been used in stature estimation. The mean age for the White males of this study is not significantly different from the Terry Collection White males by Simmons *et al.* (1990) But the mean age is significantly different from the American White males in the other studies presented for comparison. The mean femoral length of the South African White males is significantly longer than that of the Terry Collection subjects ($p<0.01$) by Simmons *et al.* (1990) and the Terry Collection subjects ($p<0.001$) by Trotter and Gleser (1952). On the other hand the mean femoral length for the South African White males is not statistically different from the Terry Collection subjects by Steele (1970), the Korean War dead by Trotter and Gleser (1958), and modern forensic science cases by Jantz and Moore–Jansen (1988).

For the Black males of South Africa, the mean femoral length is considerably shorter than the American Black males ($p<0.0001$) in all comparisons uniformly.

Interestingly, there is no statistically significant difference in the mean femoral length between South African White females and American White females presented in all the comparisons.

The mean femoral length for the South African Black females is considerably shorter than the American Black females in all cases ($p< 0.0001$).

It is interesting to observe that the mean femoral lengths of the Black group of both sexes in this study are considerably shorter than those presented for the American Blacks. This indicates the variability of the two Black groups from different sources. The mean maximum length of femur presented by Lundy (1983) for Male Black South Africans is 44.85 cm. It is quite close to the result in this study which is 44.90 cm. These differences between the American Blacks and South African Blacks point toward the necessity of population specific formulae to calculate stature and bone lengths. That is the rationale for Lundy (1983) to present regression equations for the estimation of living stature from long-limb bones based upon the anatomical method as practiced by Fully and specifically derived for the South African Blacks.

TABLE 12: MEANS AND STANDARD DEVIATIONS OF AGE (IN YEARS) AND FEMUR LENGTH (FL) (IN CENTIMETRES) OF VARIOUS SAMPLES COMPARED WITH THE PRESENT SAMPLE

STUDY	N	AGE	S.D.	p	FL	S.D.	p
WHITE MALES							
Raymond Dart*	100	57.14	10.50		46.71	2.59	
Terry [a]	200	58.73	13.88	NS	45.64	2.68	<0.01
Terry [b]	255	61.66	12.55	<0.01	45.66	2.45	<0.001
Terry [c]	61	52.97	4.98	<0.01	46.24	3.06	NS
War dead [d]	545	23.14	4.31	<0.0001	47.29	2.36	<0.05
War dead [e]	1265	–	–	–	47.17	2.30	NS
Modern [f]	113	37.26	17.08	<0.0001	47.18	2.54	NS
BLACK MALES							
Raymond Dart*	100	–	–		44.90	2.65	
Terry [a]	203	47.33	16.77	<0.01	47.47	2.93	<0.0001
Terry [b]	360	49.46	15.51	<0.0001	47.42	2.97	<0.0001
Terry [c]	42	43.25	13.21	NS	47.92	3.28	<0.0001
War dead [d]	54	25.07	4.98	<0.0001	48.34	2.26	<0.0001
War dead [e]	191	–	–	–	48.41	2.48	<0.0001
Modern [f]	29	37.45	21.52	NS	48.24	2.81	<0.0001
WHITE FEMALES							
Raymond Dart*	100	62.35	11.72		43.15	2.74	
Terry [a]	201	63.19	15.59	NS	42.71	2.36	NS
Terry [b]	63	63.93	16.07	NS	42.96	2.53	NS
Terry [c]	52	63.35	17.02	NS	42.69	2.71	NS
Modern [f]	89	37.14	21.52	<0.0001	43.72	2.02	NS
BLACK FEMALES							
Raymond Dart*	100	37.74	9.53		42.61	2.13	
Terry [a]	199	48.11	18.44	<0.0001	43.99	2.41	<0.0001
Terry [b]	177	47.21	17.65	<0.0001	43.71	2.39	<0.001
Terry [c]	57	39.58	15.52	NS	43.96	2.30	<0.001
Modern [f]	24	34.37	19.73	NS	45.52	3.23	<0.0001

* = present study
[a] = Simmons *et al.* (1990)
[b] = Trotter & Gleser (1952)
[c] = Steele & McKern (1970)
[d] = Trotter & Gleser (1952)
[e] = Trotter & Gleser (1958)
[f] = Janz & Moore-Jansen (1988)
S.D. = Standard Deviation
NS= Non-significant

He showed that the estimated statures using Trotter and Gleser's formulae are greater than when the statures are estimated using the equations derived from the South African Black sample. Since there is a considerable difference in the lengths of the femur between the American Blacks and the South African Blacks as shown in this study, Lundy's formulae are expected to be more accurate in estimating living stature in the South African Black than those derived for the American Black. In the same token, the need to present separate formulae to calculate the length of femur from its segments is clearly indicated.

Afterwards, the possibility of comparing the various segment measurements of the present study with those of other authors was contemplated. It, however, turned out to be feasible only to a certain extent owing to the absence of exactly comparable data by previous workers to compare all segments with. In other words, no other work in Black and White samples dealt with all segment measurements included in the present study. Meanwhile, two important studies in the same line are worth mentioning here. They are Simmons *et al.* (1990) and Prasad *et al.* (1996).

Simmons *et al.* (1990) have studied eight segments of the femur from the Terry Anatomical collection in an attempt to estimate stature from fragmentary femora. These segments were well defined and included vertical diameter of femoral head (VHD), vertical diameter of femoral neck (VND), upper breadth of femur (VHA), transverse diameter of mid-shaft (minimum) (WSD), bicondylar breadth (BCB), epicondylar breadth (FDL), lateral condyle height (LCH), and medial condyle height (MCH). Three of their segment measurements, namely VHD, VHA and LCH are similar to three of the six segments included in the present study. These segments according to this study in respective order are vertical diameter of the femoral head (VDH), upper breadth of the femur (VHA), and lateral condyle height (LCH). The landmarks and the methods of measurement used in this study for the three variables are identical to those of Simmons *et al.* (1990). Therefore, it is assumed to be practically feasible to compare the dimensions of these variables from the two sample sources. Table 13 presents a comparison of the means and standard deviations of the Terry collection segments by Simmons *et al.* (1990) with those of the Raymond Dart segments of the present study. The remaining three out of the six fragment measurements of the present study, namely, neck-shaft angle (NSA), neck length (NL) and intertrochanteric apical axis length (ITAAL) are identical to those of Prasad *et al.* (1996) done on Tamil Nadu subjects of Southern India. These authors have also included vertical diameter of the femoral head (VDH) which is again a common segment dealt with Simmons *et al.* (1990) and the present study. Meanwhile it seems a practical problem trying to compare the male and female samples of Southern India with the respective sexes of white or black groups of the present study. But, since it is believed that it will be of scientific interest to demonstrate racial differences in the various parameters studied, the results of Prasad *et al.* (1996) on Southern Indian subjects are presented and compared with the present (Tables 14, 15, 16).

As mentioned above, Table 13 compares the means and standard deviations of Simmons et al. (1996) segments of the Terry collection with those of the present study of Raymond Dart collection subjects. The segments presented for comparison are three, namely, upper breadth of the femur (VHA), vertical diameter of the femoral head (VDH), and lateral condyle height (LCH). These three segments are defined and measured in the same way in both studies. The only minor difference is the short-hand form used for the vertical diameter of femoral head which is VHD in Simmons et al. (1990) and VDH in the present. At a glance on Table 13, one can simply observe the following: One, the mean measurement for all three segments is significantly smaller ($p<0.0001$) in Black South Africans of both sexes than those of American Blacks of respective sex; two, the mean measurements for two variables are longer in South African White males than those of the American White males; these two variables are VHA ($p<0.0001$) and LCH ($p<0.01$); and three, the South African White females significantly exceed in two of the segments from American White females. These are VHA ($p<0.0001$) and LCH ($p<0.05$).

TABLE 13: MEANS AND STANDARD DEVIATIONS OF THE TERRY COLLECTION SEGMENTS (IN MM) BY SIMMONS *et al.* COMPARED WITH THE PRESENT STUDY

[Terry Collection: White males (N= 200), Black males (N= 203),
White females (N= 201), Black females (N= 199)].
[Present study: N=100 for each group].

SEGMENT	WHITE MALES			BLACK MALES			WHITE FEMALES			BLACK FEMALES		
	x	S.D.	p	x	S.D.	p	x	S.D.	p	x	S.D.	p
VHA mm (Terry)	99.10	5.87		98.99	5.77		88.24	5.18		88.98	5.24	
VHA mm (RD*)	103.26	6.69	***	95.67	6.62	***	91.89	8.09	***	85.47	5.09	***
VHD mm (Terry)	48.27	3.17		47.65	2.69		42.54	2.50		41.95	2.35	
VDH mm (RD*)	48.50	2.57	NS	44.97	2.82	***	42.14	2.87	NS	40.52	2.26	***
LCH mm (Terry)	41.35	2.91		42.33	3.00		36.30	2.53		37.05	2.34	
LCH mm (RD*)	42.41	2.95	**	39.05	3.20	***	37.00	2.99	*	34.06	2.46	***

RD* = Raymond Dart
X = Mean
S.D. = Standard Deviation

* $p<0.05$
** $p<0.01$
*** $p<0.0001$
NS= Non-significan

There is no statistically significant difference between the Terry Collection White males and Raymond Dart White males with regard to the mean vertical diameter of femoral head. Even though the mean vertical diameter of femoral head is slightly greater in the Terry Collection White females than that of the Raymond Dart White females, the difference doesn't reach to a level of statistical significance at the 5% level ($p = 0.2146$).

It has been shown in Table 12 and discussed that South African Blacks of both sexes have shorter femora when compared with the Black Americans of respective sex. Further more, it has been shown (Table 10) and described that South African Black males have significantly shorter femora than South African White males. Though not statistically significant, South African Black females have shorter femora than South African White females (Table11). Here, we can quite easily apprehend the practical consistency and proportionality between femoral length and the various segment measurements. Even though it is too early to confirm the statistical correlation between length of femur and segment measurements, looking at the above results a general statement can be set forth. The longer the average femoral length the greater the average segment measurement and vice versa.

Tables 14 through 16 compare corresponding segments of Prasad *et al.* (1996) on Southern India subjects with those of the South African Whites, Blacks, and the totals of the present study in that order.

TABLE 14: COMPARISON OF CORRESPONDING SEGMENTS BETWEEN TAMIL NADU SUBJECTS OF SOUTHERN INDIA AFTER PRASAD *et al.* (1996) WITH SOUTH AFRICAN WHITES OF THE PRESENT STUDY

DIMENSION				RANGE	MEAN	S.D.	S.E.M.	p
NSA°	Raymond D[a]	W male	100	105-139	124.1	6.6	0.66	
	S Indian[b]	Male	94	120-134	126.8	3.1	0.32	<0.001
	Raymond D[a]	W female	100	105-138	119.8	7.5	0.75	
	S Indian[b]	Female	77	120-136	126.5	3.9	0.44	<0.0001
NL mm	Raymond D[a]	W male	100	25-48	36.7	4.4	0.44	
	S Indian[b]	Male	94	20-40	30.0	4.1	0.43	<0.0001
	Raymond D[a]	W female	100	22-44	30.6	4.1	0.41	
	S Indian[b]	Female	77	19-40	26.4	4.0	0.46	<0.0001
ITAAL mm	Raymond D[a]	W male	100	60-82	70.8	4.7	0.47	
	S Indian[b]	Male	94	43-74	60.5	5.9	0.61	<0.0001
	Raymond D[a]	W female	100	53-80	62.6	5.1	0.51	
	S Indian[b]	Female	77	40-69	57.7	6.3	0.72	<0.0001
VDH mm	Raymond D[a]	W male	100	42-55	48.5	2.6	0.26	
	S Indian[b]	Male	94	31-60	43.0	3.8	0.39	<0.0001
	Raymond D[a]	W female	100	33-52	42.1	2.9	0.29	
	S Indian[b]	Female	77	32-44	39.1	2.6	0.29	<0.0001
FL mm	Raymond D[a]	W male	100	428-539	467.1	25.9	2.59	
	S Indian[b]	Male	94	401-532	448.6	22.5	2.32	<0.0001
	Raymond D[a]	W female	100	318-492	431.5	27.4	2.74	
	S Indian[b]	Female		325-480	417.7	23.9	2.70	<0.001

S.D. = Standard Deviation
S.E.M. = Standard Error of the Mean
[a] = Present study
[b] = Study by Prasad *et al.* (1996) on Tamil Nadu subjects of Southern India

We learn from these tables that the neck-shaft angle has a statistically significant greater mean in males, females, and the total of South Indian subjects when compared to both Whites and Blacks of the respective sexes as well as the total in the present study.

Here, consideration of each parameter for comparison is thought to be a reasonable step in order to appreciate population differences in the size of femoral dimensions with an objective support. The mean neck length of Tamil Nadu subjects in Southern India is considerably smaller in both males ($p<0.0001$) and females ($p<0.0001$) than compared to that of the South African White males and females, respectively (Table 14). Similarly South African Black males have a greater neck length than that of South Indian males ($p<0.001$). Even though female Southern Indians have a relatively smaller mean neck length than those of South African Black females, there is no statistically significant difference in this dimension between the two groups.

The mean intertrochanteric apical axis length as well is considerably greater in South African Whites of both sexes ($p<0.0001$) when compared to the respective sexes of South Indian subjects (Table 14). This segment for the South Indian male subjects (60.5mm) is smaller ($p<0.01$) than that of the Black males of South Africa (63.11mm) (Table 15). However, the mean intertrochanteric apical axis length of South Indian female subjects (57.7mm) is greater ($p<0.01$) than that of the South African Black females (55.83mm) (Table 15).

Mean vertical diameter of the head of femur in South Indian males and females is 43mm and 39.1mm respectively. The mean for South African White males and females is 48.50mm and 42.14mm, respectively. Thus, it can be seen that the VDH in South Indian males and females is considerably smaller ($p<0.0001$) than South African Whites of respective sex (Table 14). The mean length of this segment is greater in South African Black males ($p<0.0001$) and females ($p<0.001$) than in the Southern Indian subjects of respective sex (Table 15).

TABLE 15: COMPARISON OF CORRESPONDING SEGMENTS BETWEEN TAMIL NADU SUBJECTS OF SOUTHERN INDIA AFTER PRASAD *et al.* (1996) WITH SOUTH AFRICAN BLACKS OF THE PRESENT STUDY

DIMENSION				RANGE	MEAN	S.D.	S.E.M.	p
NSA°	Raymond D [a]	B male	100	105-136	121.9	5.1	0.51	
	S Indian [b]	Male	94	120-134	126.8	3.1	0.32	<0.0001
	Raymond D [a]	B f male	100	111-140	121.5	5.1	0.51	
	S Indian [b]	Female	77	120-136	126.5	3.9	0.44	<0.0001
NL mm	Raymond D [a]	B male	100	21-46	32.2	4.8	0.48	
	S Indian [b]	Male	94	20-40	30.0	4.1	0.43	<0.001
	Raymond D [a]	B f male	100	18-38	26.7	4.1	0.41	
	S Indian [b]	Female	77	19-40	26.4	4.0	0.46	NS
ITAAL mm	Raymond D [a]	B male	100	52-78	63.1	5.3	0.53	
	S Indian [b]	Male	94	43-74	60.5	5.9	0.61	<0.01
	Raymond D [a]	B f male	100	42-68	55.8	4.3	0.43	
	S Indian [b]	Female	77	40-69	57.7	6.3	0.72	<0.05
VDH mm	Raymond D [a]	B male	100	37-51	45.0	2.8	0.28	
	S Indian [b]	Male	94	31-60	43.0	3.8	0.39	<0.0001
	Raymond D [a]	B f male	100	35-46	40.5	2.3	0.23	
	S Indian [b]	Female	77	32-44	39.1	2.6	0.29	<0.001
FL mm	Raymond D [a]	B male	100	397-515	449.0	26.5	2.65	
	S Indian [b]	Male	94	401-532	448.6	22.5	2.32	NS
	Raymond D [a]	B f male	100	372-483	426.1	21.3	2.13	
	S Indian [b]	Female	77	325-480	417.7	23.9	2.70	<0.05

S.D. = Standard Deviation
S.E.M. = Standard Error of the Mean
[a] = Present study
[b] = Study by Prasad *et al.* (1996) on Tamil Nadu subjects of Southern India

The mean femoral length for South Indian subjects is 448.6 mm for males and 417.7 mm for females. Once more, the South African Whites of both sexes quite appreciably exceed the South Indians of respective sex in this regard (Table 14). It is 467.1 mm (p<0.0001) and 431.5 mm (p<0.001) for South African White males and females, respectively. The mean femoral length of the South African Black males (449.03m) is quite close to that of South Indian male subjects (Table 15). Even though the South African Black males have a slightly greater mean femoral length than that of the South Indian males, the difference is not statistically significant. However, the mean femoral length for Black South African females (426.07 mm) is greater ($p<0.05$) than that of the South Indian female subjects.

From Table 16, one can generally observe that the mean measurements of all dimensions in the total for the South Indian subjects are significantly different from the total sample of South African subjects of the present study. Hence it is clearly evident that the equations developed by Prasad *et al.* (1996) using skeletal material of South Indian subjects can not be applied to the South African population groups. Even though the authors explained the robustness of their models, the equations should remain population specific as different populations are morphologically distinct. This has been demonstrated in the present study by the comparisons between South African population groups and Tmil Nadu subjects of Southern India.

TABLE 16: COMPARISON OF CORRESPONDING SEGMENTS IN THE TOTAL SAMPLE OF TAMIL NADU SUBJECTS OF SOUTHERN INDIA AFTER PRASAD *et al.* (1996) WITH THE TOTAL SAMPLE OF THE PRESENT STUDY

DIMENSION			RANGE	MEAN	S.D.	S.E.M.	p
NSA°	Raymond D[a]	400	105-140	121.8	6.3	0.32	
	S Indian[b]	171	120-136	126.8	3.1	0.44	<0.0001
NL mm	Raymond D[a]	400	18-48	31.5	5.6	0.28	
	S Indian[b]	171	19-44	28.4	4.5	0.34	<0.0001
ITAAL mm	Raymond D[a]	400	42-82	63.1	7.2	0.34	
	S Indian[b]	171	40-74	57.9	6.7	0.52	<0.0001
VDH mm	Raymond D[a]	400	33-55	40.0	4.0	0.20	
	S Indian[b]	171	31-60	41.2	3.8	0.94	<0.001
FL mm	Raymond D[a]	400	318-539	443.4	30.0	1.50	
	S Indian[b]	171	325-532	434.7	27.8	2.10	<0.01

S.D. = Standard Deviation

S.E.M. = Standard Error of Mean

[a] = Present study

[b] = Study by Prasad *et al.* (1996) on Tamil Nadu subjects of Southern India

3.4 CORRELATION ANALYSIS BETWEEN FEMUR LENGTH AND OTHER SEGMENT MEASUREMENTS

Table 17 presents the correlation analysis relating femur length with neck-shaft angle, neck length, intertrochanteric apical axis length, maximum vertical diameter of the femoral head, upper breadth of the femur, and lateral condyle height. The table includes correlation coefficients between femur length and the other segments to show the numerical association between them. In addition, the significance level of the association between length of femur and each fragment measurement is indicated in order to permit determination of the strength of correlation just by inspection.

In general, femoral length showed a highly significant and positive correlation with all its fragments in all the Whites and Blacks of both sexes. As can be viewed from the table, all fragment measurements are correlated to femoral length at the 0.01% significance level ($p<0.0001$) in all groups except the neck-shaft angle in the case of Black females. Even in the Black females, though the numerical value of the correlation coefficient between femur length and NSA ($r = 0.2625$) appears to be relatively lower, there is still a significant correlation at the 1% significance level ($p<0.01$).

If one examines just the numerical values of the coefficients of correlation between femur length and the other variables, there is a relative difference in the different groups included.

There is a strong correlation between femur length and neck-shaft angle for the White males and White females with a numerical value of 0.8449 and 0.8933, respectively. They are significantly correlated in both ($p<0.0001$). The coefficient of correlation between femur length and neck-shaft angle in the Black males is 0.5632 which is relatively smaller than those of the Whites of both sexes. But still, the correlation is highly significant ($p<0.0001$). In the Black females, the correlation coefficient between length of femur and neck-shaft angle is quite lower than those of all the other groups. This directs us to the presence of a racial and sex difference in the neck-shaft angle section. Besides, we learn from this that neck-shaft angle has a relatively lower predictive capability for estimating femur length in the Black females when compared to the others.

TABLE 17: CORRELATION COEFFICIENTS BETWEEN LENGTH OF FEMUR AND FRAGMENT MEASUREMENTS FOR RACE AND SEX

	WHITE MALES (n = 100)	BLACK MALES (n = 100)	WHITE FEMALES (n = 100)	BLACK FEMALES (n = 100)	TOTAL (n = 400)
NSA	0.8449 (p<.0001)	0.5632 (p<0.0001)	0.8933 (p<0.0001)	0.2625 (p<0.01)	0.6772 (p<0.0001)
NL	0.8575 (p<.0001)	0.8000 (p<0.0001)	0.8297 (p<0.0001)	0.6375 (p<0.0001)	0.8402 (p<0.0001)
ITAAL	0.7653 (p<.0001)	0.7899 (p<0.0001)	0.7951 (p<0.0001)	0.7571 (p<0.0001)	0.8076 (p<0.0001)
VDH	0.5982 (p<0.0001)	0.6780 (p<0.0001)	0.6481 (p<0.0001)	0.6339 (p<0.0001)	0.7593 (p<0.0001)
VHA	0.7999 (p<0.0001)	0.8027 (p<0.0001)	0.8381 (p<0.0001)	0.6796 (p<0.0001)	0.8422 (p<0.0001)
LCH	0.8066 (p<.0001)	0.7674 (p<0.0001)	0.8066 (p<0.0001)	0.7019 (p<0.0001)	0.8305 (p<0.0001)

Neck length is significantly and positively correlated ($p<0.0001$) with length of femur in all groups and so do the upper breadth of femur, lateral condyle height, maximum vertical diameter of femoral head, and intertrochanteric apical axis length. In White males, the most highly correlated segment with length of femur is neck length with a correlation coefficient of 0.8575. The other three segments having a higher correlation with femur length in White males are neck-shaft angle, lateral condyle height, and upper breadth of femur with correlation coefficients being 0.8449, 0.8066, and 0.7999 in respective order. In Black males, the three segments which demonstrated a higher correlation with length of femur are upper breadth of femur, neck length, and intertrochanteric apical axis length with correlation coefficients of 0.8027, 0.8000 and 0.7899, respectively. In White females, all the segments are highly correlated to femur length with five out of six segments having coefficients of correlation above or close to 0.8. Neck-shaft angle is the single most segment which demonstrated the highest correlation with femur length with a correlation coefficient of 0.8933. The other three variables in White females which showed a higher correlation with femur length are upper breadth of femur (r = 0.8381), neck length (r = 0.8297), and lateral condyle height (r = 0.8066).

The coefficients of correlation in Black females are in general lower for all variables when compared to the other groups except for vertical diameter of femoral head which demonstrated a somewhat higher correlation coefficient than that of the White males. The three segments, which showed a higher correlation in Black females in respective order, are intertrochanteric apical axis length, (r = 0.7571), lateral condyle height (r = 0.7019), and upper breadth of femur (r = 0.6796).

Correlation coefficients of the total sample were also examined without consideration of race and sex (Table 17). From this, one could learn which variables demonstrated higher coefficients of correlation consistently in all groups. It is upper breadth of the femur, which showed the highest correlation coefficient in the total sample with a numerical value of 0.8422 ($p<0.0001$). The other three variables with higher coefficients of correlation in the total sample in descending order are neck length (r = 0.8402), lateral condyle height (r = 0.8305), and intertrochanteric apical axis length (r = 0.8076).

According to Table 17, there is a statistically significant correlation between femur length and other segment measurements consistent in all groups of the study sample. Correlations between femoral length and segment measurements have also been shown by other authors (Simmons *et al.*, 1990; Prasad *et al.*, 1996; Isaac *et al.*, 1997). Isaac *et al.* (1997) showed that in the generally short statured South Indian individuals, the femoral length is shorter; the neck-shaft angle, length of the neck, intertrochanteric apical axis length, and maximum vertical diameter of the head are smaller; thereby, the femoral neck is oblique. Thus it is justified to say that the taller the individual, the steeper the femoral neck. The observed correlations in the present study establish the high predictive capability of the studied segments for estimation of femoral length. This information has applicability in forensic medicine and physical anthropology. When only a fragment from the proximal or distal end of the femur is available in forensic work, as is often the case, that retained segment can be utilized for estimating femur length and living stature of the individual. A question can arise here as to which segments to select among others for the determination of femoral length and living stature. In general, fragments with a higher coefficient of correlation are good indicators of femoral length and have a higher predictive capability than others. For instance, according to the results of the present study, it would be recommended to refrain from using neck-shaft angle as an estimator of femoral length in Black females when the other segments can be defined and measured clearly. Utilizing two or more combination of segments may provide a higher predictive efficiency than relying on a single segment.

3.5 COMPARISON OF CORRELATION COEFFICIENTS OF THE PRESENT WITH OTHER STUDIES

It was also attempted to compare correlation coefficients of corresponding segments from other authors with the present. Table 18 shows a comparison of three segments (upper breadth of femur, maximum vertical diameter of femur head, and lateral condyle height) with those of Terry Collection segments by Simmons *et al.* (1990). For both races and sexes, all the correlation coefficients of corresponding segments are consistently higher in the present study than those of Simmons *et al.* (1990) for the Terry Collection subjects. The correlation coefficients for maximum vertical diameter of head of femur from both studies in corresponding population groups are more or less comparable indicating a similar predictive efficiency of this segment in the two different samples. Otherwise, upper breadth of the femur as well as lateral condyle height showed considerably higher coefficients of correlation in the present study than those by Simmons *et al.* (1990). This indicates a higher predictive efficiency of these segments in the present study.

TABLE 18: COMPARISON OF CORRELATION COEFFICIENTS OF TERRY COLLECTION SEGMENTS BY SIMMONS *et al.* (1990) WITH THE PRESENT STUDY

	TERRY COLLECTION			PRESENT STUDY		
	VHA	VDH	LCH	VHA	VDH	LCH
White males	0.606	0.526	0.571	0.800	0.598	0.807
Black male	0.592	0.454	0.452	0.803	0.678	0.767
White females	0.632	0.596	0.665	0.838	0.648	0.807
Black females	0.513	0.585	0.585	0.680	0.634	0.702

Table 19 indicates a comparison of correlation coefficients for four segments from Prasad *et al.* (1996) with corresponding segments in the present study. The fragments compared are neck-shaft angle, neck length, intertrochanteric apical axis length, and maximum vertical diameter of head of femur. Here, comparison is made with the total sample of the present study without considering race and sex. All correlation coefficients of the present study are considerably higher for all corresponding segments than those presented by Prasad *et al.* (1996) for South Indian subjects. Once more, this establishes the very high predictive efficiency of segments included in the present study for the specified population groups. However, it is still worth mentioning that the correlation coefficient between femoral length and neck-shaft angle in the Black females (r = 0.2625) is lower than the corresponding coefficient in the females of the Prasad *et al.* (1996) study (r = 0.2762). This indicates neck-shaft angle in the Black females of the present study has a lower predictive value for estimating femur length and stature.

TABLE 19: COMPARISON OF CORRELATION COEFFICIENTS OF FOUR SEGMENTS FROM SOUTH INDIAN SUBJECTS BY PRASAD *et al.* (1996) WITH THE PRESENT STUDY

SEGMENTS	PRASAD *et al.* (n = 171)	PRESENT STUDY (n = 400)
NSA	0.2575	0.6772
NL	0.4749	0.8402
ITAAL	0.4714	0.8076
VDH	0.5355	0.7593

3.6 INTERCORRELATION MATRICES AMONG THE VARIOUS SEGMENT MEASUREMENTS

So far we examined the correlation that existed between femur length and the other six segment measurements. Here, the intercorrelations of all fragment measurements among each other are examined. The intercorrelation matrices illustrate how each segment is interrelated to the other independent segment. Tables 20 through 24 present the complete matrices of intercorrelations among the six fragment measurements for White males, Black males, White females, Black females and the total sample, respectively. The level of significance is also included for each correlation coefficient in order to show the strength of association between two segments of interest.

In the White males, all the six segment measurements are significantly intercorrelated to each other ($p<0.0001$) uniformly without any exception. In Black males, the correlation between NSA and VDH is 0.3188 ($p<0.01$). All the other intercorrelations among segments are highly significant at the 0.01% level ($p<0.0001$). In White females, all segments are significantly intercorrelated ($p<0.0001$). Lateral condyle height and vertical diameter of head of femur are correlated at the 0.1% level ($p<0.01$).

TABLE 20: INTERCORRELATION MATRICES AMONG THE SIX FRAGMENT MEASUREMENTS IN SOUTH AFRICAN WHITE MALES (n = 100)

	NSA	NL	ITAAL	VDH	VHA	LCH
NSA	1					
NL	0.7529 (<p0.0001)	1				
ITAAL	0.6767 (p<0.0001)	0.8617 (p<0.0001)	1			
VDH	0.5542 (p<0.0001)	0.5388 (p<0.0001)	0.6672 (p<0.0001)	1		
VHA	0.7416 (p<0.0001)	0.8271 (p<0.0001)	0.8559 (p<0.0001)	0.6998 (p<0.0001)	1	
LCH	0.6980 (p<0.0001)	0.7486 (p<0.0001)	0.7584 (p<0.0001)	0.6905 (p<0.0001)	0.7963 (p<0.0001)	1

TABLE 21: INTERCORRELATION MATRICES AMONG THE SIX FRAGMENT MEASUREMENTS IN SOUTH AFRICAN BLACK MALES (n = 100)

	NSA	NL	ITAAL	VDH	VHA	LCH
NSA	1					
NL	0.5302 (<p0.0001)	1				
ITAAL	0.5149 (p<0.0001)	0.8373 (p<0.0001)	1			
VDH	0.3188 (p<0.01)	0.5791 (p<0.0001)	0.7113 (p<0.0001)	1		
VHA	0.4737 (p<0.0001)	0.7979 (p<0.0001)	0.8528 (p<0.0001)	0.7195 (p<0.0001)	1	
LCH	0.4940 (p<0.0001)	0.6990 (p<0.0001)	0.7312 (p<0.0001)	0.6470 (p<0.0001)	0.7760 (p<0.0001)	1

TABLE 22: INTERCORRELATION MATRICES AMONG THE SIX FRAGMENT MEASUREMENTS IN SOUTH AFRICAN WHITE FEMALES
(n = 100)

	NSA	NL	ITAAL	VDH	VHA	LCH
NSA	1					
NL	0.8677 (<p0.0001)	1				
ITAAL	0.8046 (p<0.0001)	0.8436 (p<0.0001)	1			
VDH	0.6311 (p<0.0001)	0.6466 (p<0.0001)	0.8074 (p<0.0001)	1		
VHA	0.8245 (p<0.0001)	0.8421 (p<0.0001)	0.8992 (p<0.0001)	0.8050 (p<0.0001)	1	
LCH	0.8007 (p<0.0001)	0.8007 (p<0.0001)	0.8625 (p<0.0001)	0.7786 (p<0.0001)	0.8654 (p<0.0001)	1

TABLE 23: INTERCORRELATION MATRICES AMONG THE SIX FRAGMENT MEASUREMENTS IN SOUTH AFRICAN BLACK FEMALES
(n = 100)

	NSA	NL	ITAAL	VDH	VHA	LCH
NSA	1					
NL	0.1879 (N.S.)	1				
ITAAL	0.1937 (N.S.)	0.7714 (p<0.0001)	1			
VDH	0.1383 (N.S.)	0.4390 (p<0.0001)	0.7340 (p<0.0001)	1		
VHA	0.2348 (p<0.05)	0.6591 (p<0.0001)	0.8083 (p<0.0001)	0.7079 (p<0.0001)	1	
LCH	0.2615 (p<0.01)	0.4987 (p<0.0001)	0.7057 (p<0.0001)	0.7325 (p<0.0001)	0.6207 (p<0.0001)	1

N.S.. = Not significant

However, in the case of Black females, the NSA is not correlated to three segments at the 5% critical level. These segments are NL, ITAAL, and VDH and the correlations between NSA and these segments are 0.1879, 0.1937, and 0.1383 respectively. The correlation between NSA and VHA is 0.2348 ($p<0.05$) while the correlation between NSA and LCH is 0.2615 ($p<0.01$). Apart from these exceptions, all the other segments in Black females are significantly intercorrelated to each other ($p<0.0001$). In the total sample, without consideration of race and sex (Table 24), all segment measurements are significantly intercorrelated to each other ($p<0.0001$) uniformly.

TABLE 24: INTERCORRELATION MATRICES AMONG THE SIX FRAGMENT MEASUREMENTS IN THE TOTAL SAMPLE (n = 400)

	NSA	NL	ITAAL	VDH	VHA	LCH
NSA	1					
NL	0.5647 (<p0.0001)	1				
ITAAL	0.4954 (p<0.0001)	0.8968 (p<0.0001)	1			
VDH	0.4354 (p<0.0001)	0.7501 (p<0.0001)	0.8521 (p<0.0001)	1		
VHA	0.5639 (p<0.0001)	0.8747 (p<0.0001)	0.9195 (p<0.0001)	0.8648 (p<0.0001)	1	
LCH	0.5312 (p<0.0001)	0.8285 (p<0.0001)	0.8805 (p<0.0001)	0.8607 (p<0.0001)	0.8890 (p<0.0001)	1

From the intercorrelation matrices presented, we could see that the segment measurements are positively and significantly intercorrelated to each other in both races and sexes. The only exception is the NSA in the case of Black females that showed poor intercorrelation with the other segments.

3.7 REGRESSION ANALYSIS

In this section, simple and multiple regression models for the estimation of femur length from a single segment measurement and from combinations of segments are presented.

3.7.1 SIMPLE LINEAR REGRESSION EQUATIONS

Femur length is regressed on the various segment measurements and the best fitting simple linear regression equations based on the least squares method are presented for each sex and race.

3.7.1.1 SIMPLE LINEAR REGRESSION EQUATIONS FOR ESTIMATING FEMUR LENGTH FROM SEGMENT MEASUREMENTS IN SOUTH AFRICAN WHITE MALES

Femur length is regressed against the various segments and the regression constants are presented in Table 25. It presents the slopes (with standard errors), intercepts (with standard errors), coefficients of determination, significances of the coefficients of regression and standard errors of estimates. Therefore, the values of FL (in centimetres) which is the dependent variable (y) can be predicted for any values of each segment measurement (x) (predictor variable). The linear relationship existing between FL cm and the other segments, could be presented in the form of a straight line equation, y = a + bx, where 'a' is the intercept (which is a constant), 'b' is the slope of the equation, 'y' is the dependent variable, and 'x' is the predictor variable (one of segment measurements). The linear relation between femoral length and the other segment measurements in South African White males is shown in Fig. 3. Thus, to estimate femur length (cm) using NL, one takes the slope times NL and adds the intercept. The standard error of estimate then provides an indication of the likely range within which the true length of femur is likely to fall. The following formulae are derived for South African White males to calculate femur length (in centimetres) from each fragment measurement:

1) Using neck-shaft angle:
$\text{FL cm} = 5.26 + 0.33\ (\text{NSA}^\circ) \pm 1.39$

2) Using neck length:
$\text{FL cm} = 28.26 + 0.50\ (\text{NL mm}) \pm 1.34$

3) Using intertrochanteric apical axis length:
$\text{FL cm} = 16.63 + 0.42\ (\text{ITAAL mm}) \pm 1.68$

4) Using vertical diameter of femur head:
$\text{FL cm} = 17.41 + 0.60\ (\text{VDH mm}) \pm 2.09$

5) Using upper breadth of the femur:
$\text{FL cm} = 14.71 + 0.31\ (\text{VHA mm}) \pm 1.56$

6) Using lateral condyle height:
$\text{FL cm} = 16.61 + 0.71\ (\text{LCH mm}) \pm 1.54$

For example, a NL dimension of 30 mm for a White male would be used to estimate femur length (cm) as follows:

$$\begin{aligned}
\text{FL cm} &= 28.26 + 0.50\ (\text{NL mm}) \pm 1.34 \\
&= 28.26 + 0.50 \times 30 \pm 1.34 \\
&= 28.26 + 15 \pm 1.34 \\
&= 43.26 \pm 1.34
\end{aligned}$$

The femur length would be 43.26 cm and there is a 95% probability that the true value of femur length lies between 43.26 – 1.34 cm and 43.26 + 1.34 cm (i.e., between 41.92 cm and 44.6 cm).

TABLE 25: REGRESSION CONSTANTS FOR ESTIMATING FEMUR LENGTH IN CENTIMETRES, FROM VARIOUS FEMUR FRAGMENTS IN SOUTH AFRICAN WHITE MALES (n = 100)

SEGMENT	b^a	S.E. (b)	A^b	S.E. (a)	r^{2c}	t^d	S.E.E. ^{e}
NSA°	0.33	0.02	5.26	2.65	0.71	15.64 ($p<0.0001$)	1.39
NL mm	0.50	0.03	28.26	1.13	0.74	16.50 ($p<0.0001$)	1.34
ITAAL mm	0.42	0.04	16.63	2.56	0.59	11.77 ($p<0.0001$)	1.68
VDH mm	0.60	0.08	17.41	3.97	0.36	7.39 ($p<0.0001$)	2.09
VHA mm	0.31	0.02	14.71	2.43	0.64	13.19 ($p<0.0001$)	1.56
LCH mm	0.71	0.05	16.61	2.23	0.65	13.51 ($p<0.0001$)	1.54

[a] = Coefficient of regression (slope)

[b] = Intercept

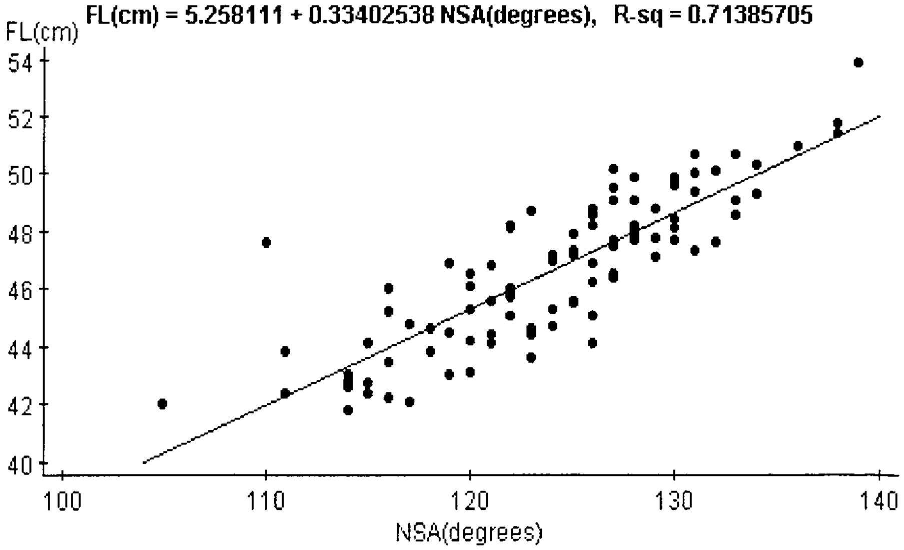
[c] = Square of coefficient of correlation called coefficient of determination

[d] = Significance of b

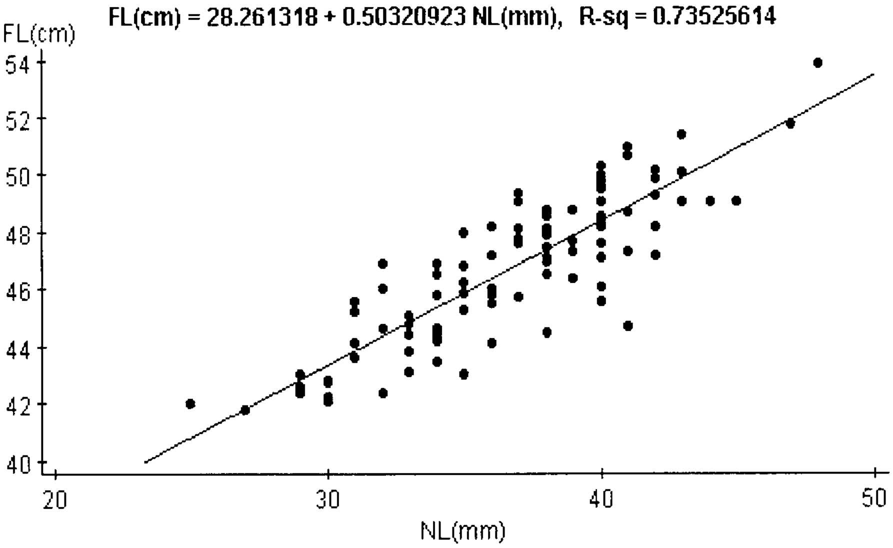
[e] = Standard error of estimate

FIGURE 3 (a-f): SCATTER PLOTS AND REGRESSION LINES OF FEMORAL LENGTH (ORDINATE) AGAINST EACH SEGMENT MEASURENT (ABSCISSA) FOR SOUTH AFRICAN WHITE MALES

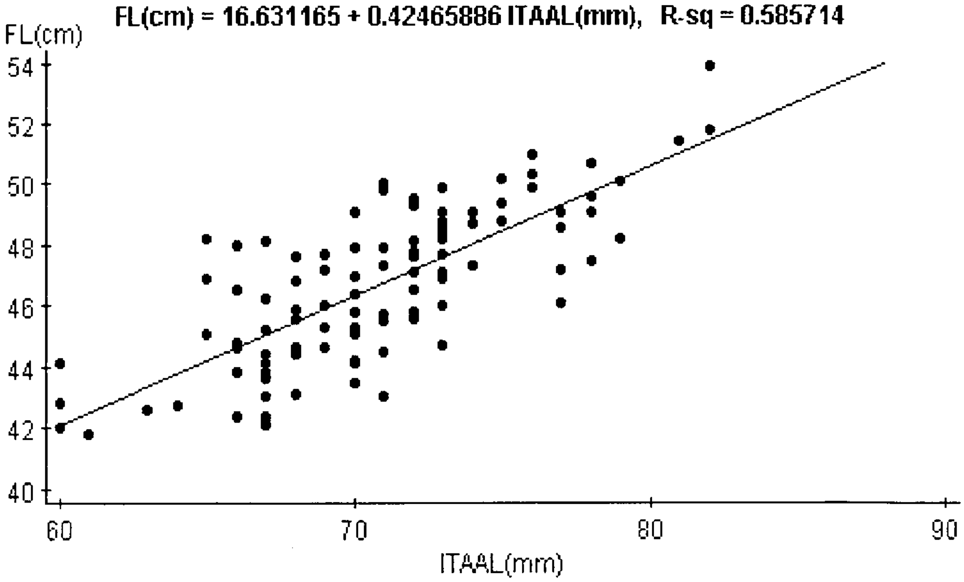
a)



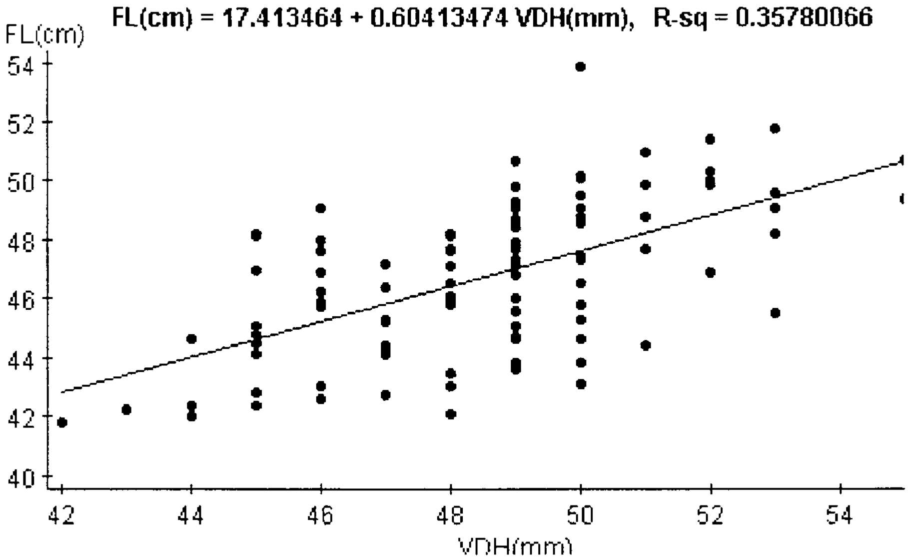
b)


FL(cm) = 28.261318 + 0.50320923 NL(mm), R-sq = 0.73525614
FL(cm)
54
52
50
48
46
44
42
40
20
30
40
50
NL(mm)

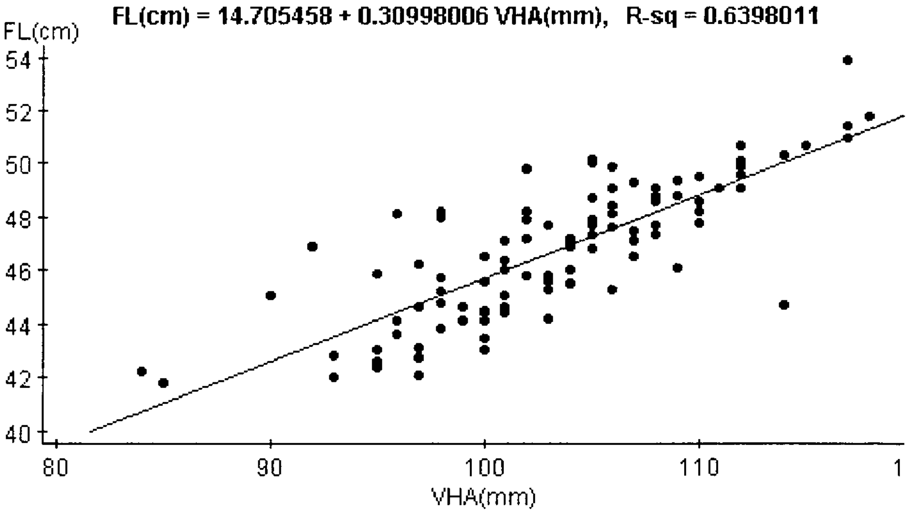
c)


FL(cm) = 16.631165 + 0.42465886 ITAAL(mm), R-sq = 0.585714
FL(cm)
54
52
50
48
46
44
42
40
60
70
80
90
ITAAL(mm)

d)


FL(cm) = 17.413464 + 0.60413474 VDH(mm), R-sq = 0.35780066
FL(cm)
54
52
50
48
46
44
42
40
42
44
46
48
50
52
54
VDH(mm)

e)


FL(cm) = 14.705458 + 0.30998006 VHA(mm), R-sq = 0.6398011
FL(cm)
54
52
50
48
46
44
42
40
80
90
100
110
1
VHA(mm)

f)

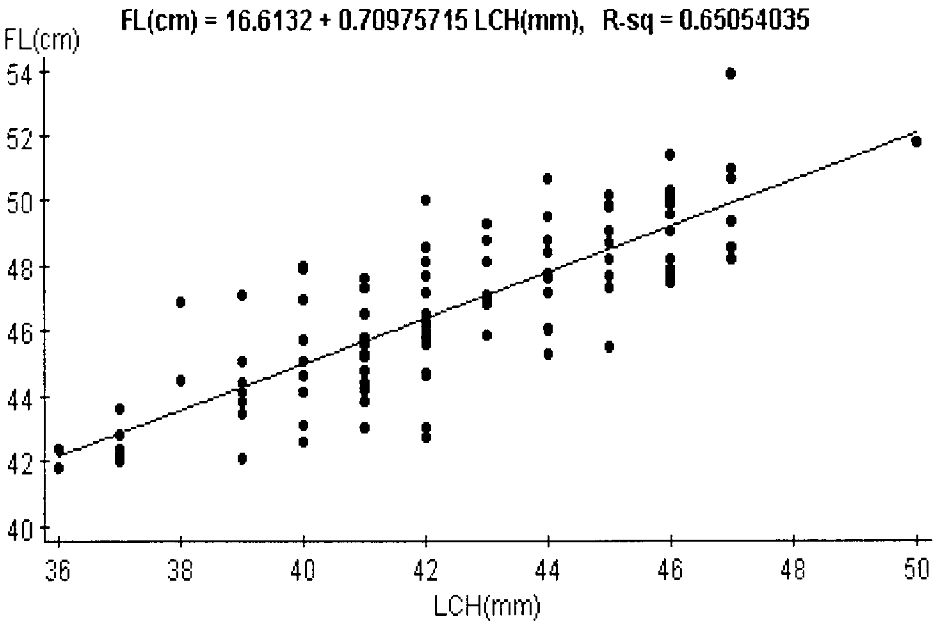


TABLE 26: REGRESSION CONSTANTS FOR ESTIMATING FEMUR LENGTH IN CENTIMETRES, FROM VARIOUS FEMUR FRAGMENTS IN SOUTH AFRICAN BLACK MALES (n = 100)

SEGMENT	b [a]	S.E. (b)	A [b]	S.E. (a)	r^{2c}	t [d]	S.E.E. [e]
NSA°	0.29	0.04	9.59	5.24	0.32	6.75 ($p<0.0001$)	2.20
NL mm	0.44	0.03	30.82	1.08	0.64	13.20 ($p<0.0001$)	1.60
ITAAL mm	0.40	0.03	19.89	1.97	0.62	12.75 ($p<0.0001$)	1.63
VDH mm	0.63	0.07	16.30	3.14	0.46	9.13 ($p<0.0001$)	1.95
VHA mm	0.32	0.02	14.21	2.31	0.64	13.32 ($p<0.0001$)	1.59
LCH mm	0.63	0.05	20.14	2.10	0.59	11.85 ($p<0.0001$)	1.70

[a] = Coefficient of regression (slope)
[b] = Intercept
[c] = Square of coefficient of correlation called coefficient of determination
[d] = Significance of b
[e] = Standard error of estimate

TABLE 27: REGRESSION CONSTANTS FOR ESTIMATING FEMUR LENGTH IN CENTIMETRES, FROM VARIOUS FEMUR FRAGMENTS IN SOUTH AFRICAN WHITE FEMALES (n = 100)

SEGMENT	b [a]	S.E. (b)	A [b]	S.E. (a)	r [2c]	t [d]	S.E.E. [e]
NSA°	0.33	0.02	4.03	1.99	0.80	19.68 ($p<0.0001$)	1.24
NL mm	0.55	0.04	26.22	1.16	0.69	14.72 ($p<0.0001$)	1.54
ITAAL mm	0.43	0.03	16.15	2.09	0.63	12.98 ($p<0.0001$)	1.67
VDH mm	0.62	0.07	17.10	3.10	0.42	8.42 ($p<0.0001$)	2.10
VHA mm	0.28	0.02	17.08	1.72	0.70	15.21 ($p<0.0001$)	1.50
LCH mm	0.74	0.05	15.83	2.03	0.62	13.51 ($p<0.0001$)	1.63

[a] = Coefficient of regression (slope)
[b] = Intercept
[c] = Square of coefficient of correlation called coefficient of determination
[d] = Significance of b
[e] = Standard error of estimate

3.7.1.2 SIMPLE LINEAR REGRESSION EQUATIONS FOR ESTIMATING FEMUR LENGTH FROM SEGMENT MEASUREMENTS IN SOUTH AFRICAN BLACK MALES

Femur length is regressed against the various segments and the regression constants are presented in Table 26. The table presents slopes (with standard errors), intercepts (with standard errors), coefficients of determination, significances of the coefficients of regression, and standard errors of estimates. Therefore, the values of FL (in centimetres), which is the dependent variable, 'y' could be predicted for any values of each segment measurement 'x' (predictor variable). The linear relationship existing between FL cm and each segment is presented in the form of a straight line equation, $y = a + bx$, where 'a' is the intercept (which is a constant), and 'b' is the slope of the equation. The linear relation between femoral length and the other segment measurements in South African Black males is shown in Fig. 4.

The following formulae are derived for South African Black males for estimating femur length (in centimetres) from each fragment measurement:

1) Using neck-shaft angle:
FL cm = 9.59 + 0.29 (NSA°) ± 2.20

2) Using neck length:
FL cm = 30.82 + 0.44 (NL mm) ± 1.60

3) Using intertrochanteric apical axis length:
FL cm = 19.89 + 0.40 (ITAAL mm) ± 1.63

4) Using vertical diameter of femur head:
FL cm = 16.30 + 0.63 (VDH mm) ± 1.95

5) Using upper breadth of the femur:
FL cm = 14.21 + 0.32 (VHA mm) ± 1.59

6) Using lateral condyle height:
FL cm = 20.14 + 0.63 (LCH mm) ± 1.70

3.7.1.3 SIMPLE LINEAR REGRESSION EQUATIONS FOR ESTIMATING FEMUR LENGTH FROM SEGMENT MEASUREMENTS IN SOUTH AFRICAN WHITE FEMALES

Femur length is regressed on the various segment measurements and the regression constants are presented in Table 27. The table presents slopes (with standard errors), intercepts (with standard errors), coefficients of determination, significances of the coefficient of regression, and standard errors of estimates. Based on this table, the linear relationship existing between FL cm and the other segment measurements could be depicted in the form of a straight line equation (y = a + b x), where 'y' is the outcome variable (FL cm), 'a' is the intercept, 'b' is the slope of the equation, and 'x' is the predictor variable. This linear relation between femoral length and the other segment measurements in South African White females is shown in Fig. 5.

Thus, the following formulae can be applied for South African White females to predict femur length for any value of each segment:

1) Using neck-shaft angle:
FL cm = 4.03 + 0.33 (NSA°) ± 1.24

2) Using neck length:
FL cm = 26.22 + 0.55 (NL mm) ± 1.54

3) Using intertrochanteric apical axis length:
FL cm = 16.15 + 0.43 (ITAAL mm) ± 1.67

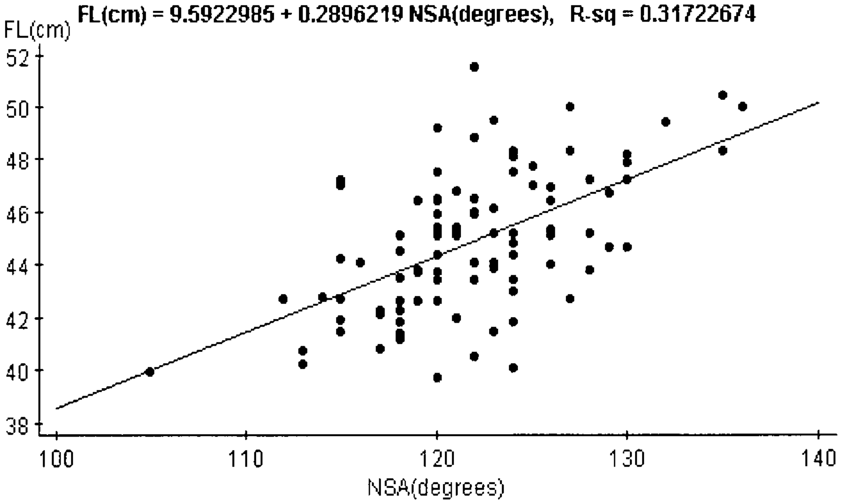
4) Using vertical diameter of femur head:
FL cm = 17.10 + 0.62 (VDH mm) ± 2.10

5) Using upper breadth of the femur:
FL cm = 17.08 + 0.28 (VHA mm) ± 1.50

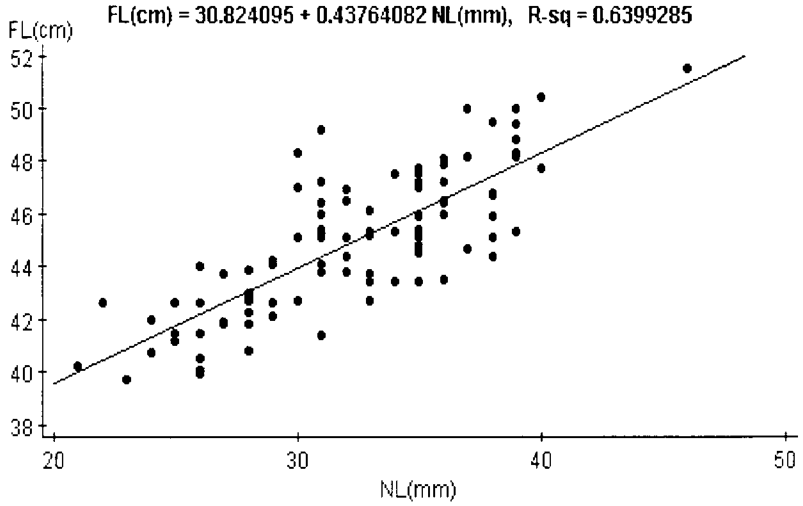
6) Using lateral condyle height:
FL cm = 15.83 + 0.74 (LCH mm) ± 1.63

FIGURE 4(a-f): SCATTER PLOTS AND REGRESSION LINES OF FEMORAL LENGTH (ORDINATE) AGAINST EACH SEGMENT MEASUREMENT (ABSCISSA) FOR SOUTH AFRICAN BLACK MALES

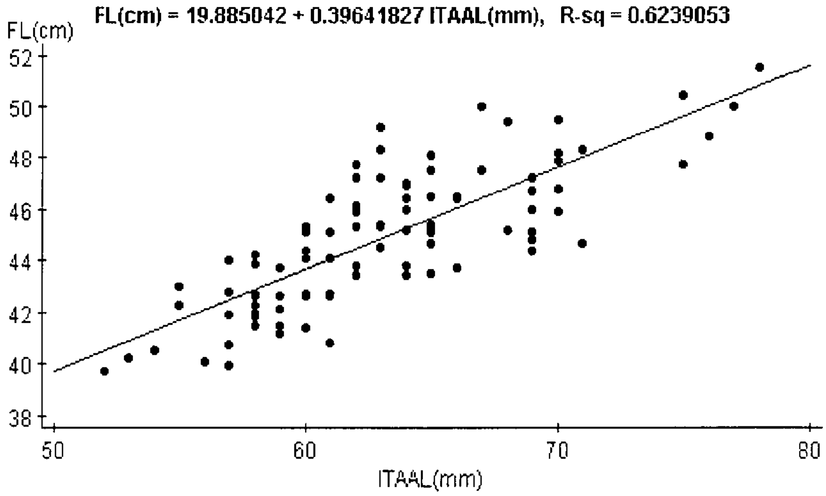
a)



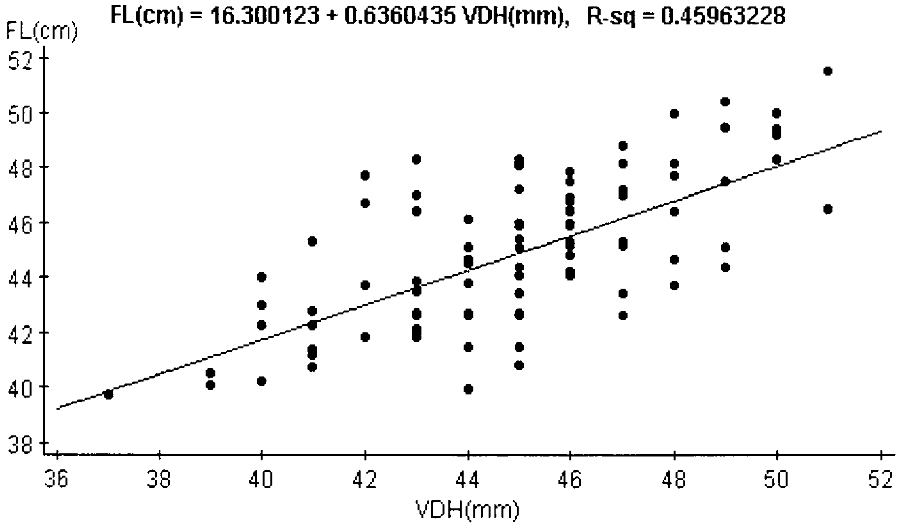
b)


FL(cm) = 30.824095 + 0.43764082 NL(mm), R-sq = 0.6399285
FL(cm)
52
50
48
46
44
42
40
38
20
30
40
50
NL(mm)

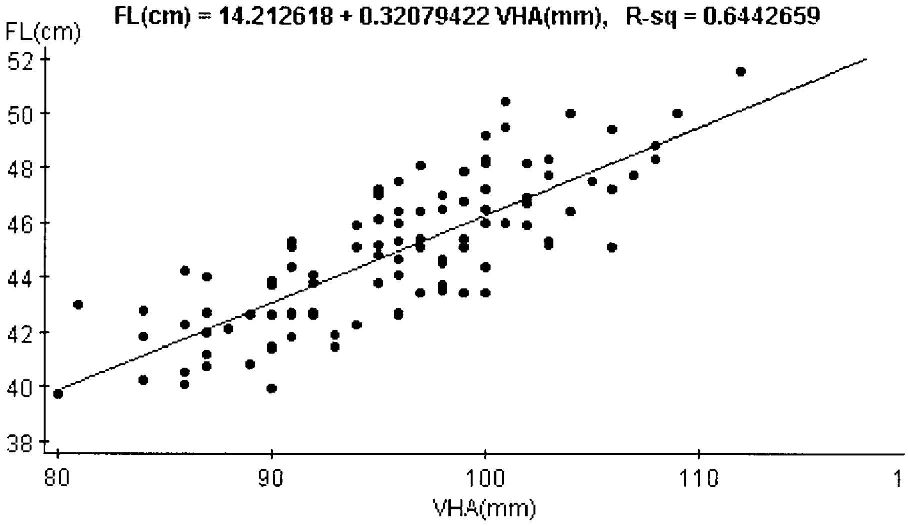
c)


FL(cm) = 19.885042 + 0.39641827 ITAAL(mm), R-sq = 0.6239053
FL(cm)
52
50
48
46
44
42
40
38
50
60
70
80
ITAAL(mm)

d)


FL(cm) = 16.300123 + 0.6360435 VDH(mm), R-sq = 0.45963228

e)


FL(cm) = 14.212618 + 0.32079422 VHA(mm), R-sq = 0.6442659

f)

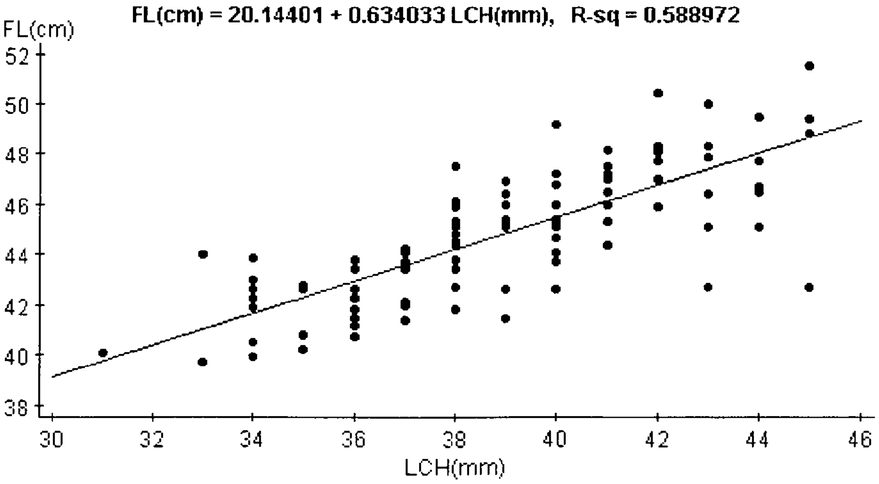
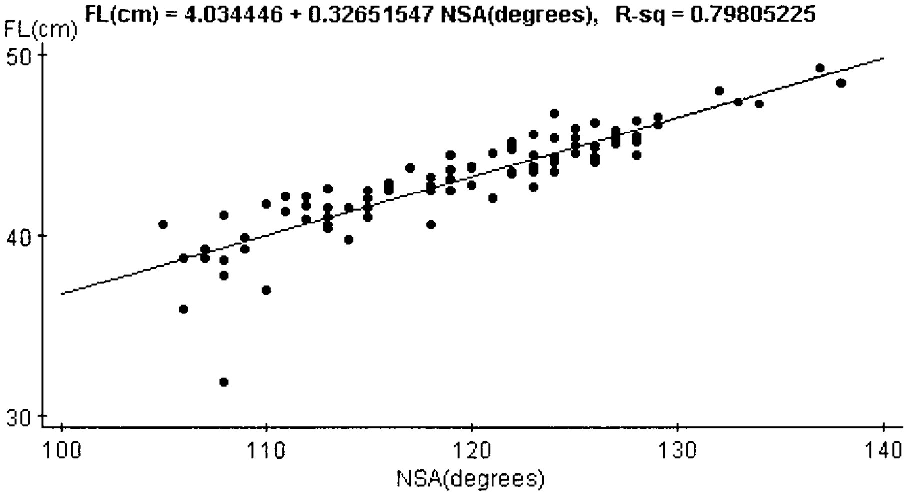
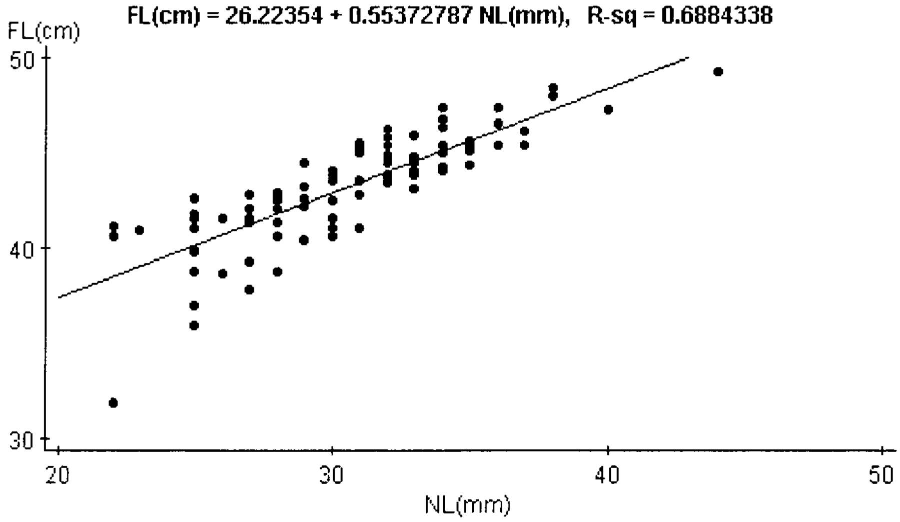

FL(cm) = 20.14401 + 0.634033 LCH(mm), R-sq = 0.588972

FIGURE 5(a-f) SCATTER PLOTS AND REGRESSION LINES OF FEMORAL LENGTH (ORDINATE) AGAINST EACH SEGMENT MEASUREMENT (ABSCISSA) FOR SOUTH AFRICAN WHITE FEMALES

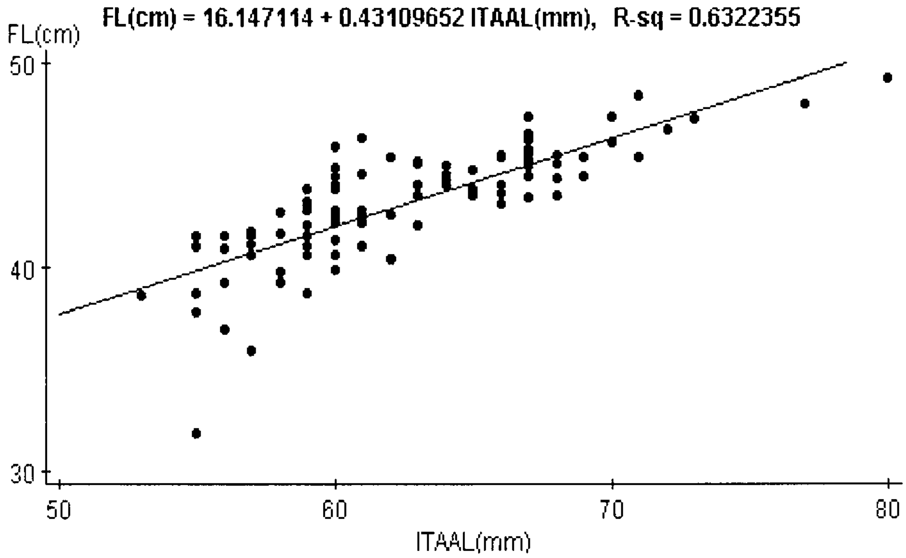
a)



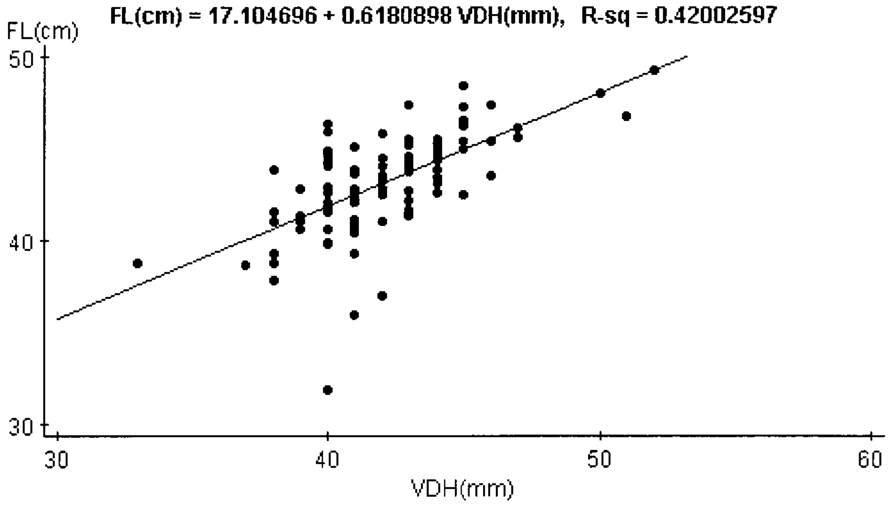
b)



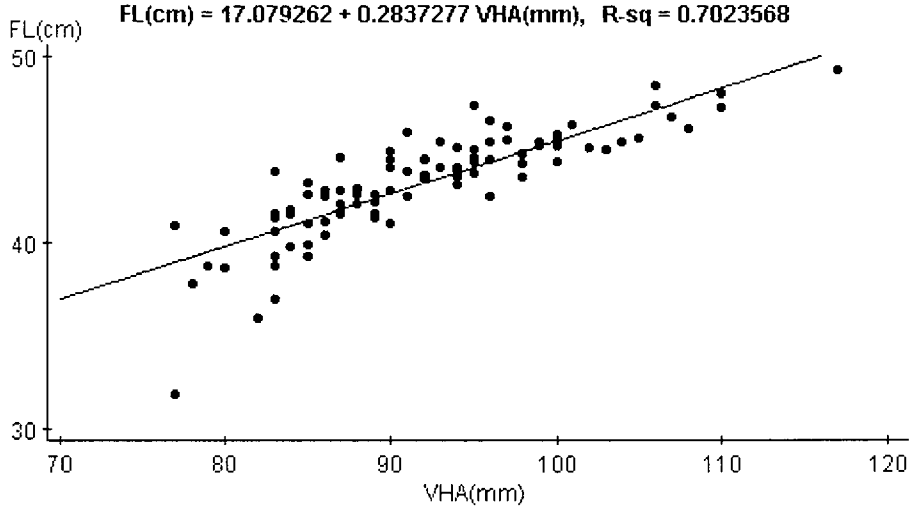
c)


FL(cm) = 16.147114 + 0.43109652 ITAAL(mm), R-sq = 0.6322355
FL(cm)
50
40
30
50
60
70
80
ITAAL(mm)

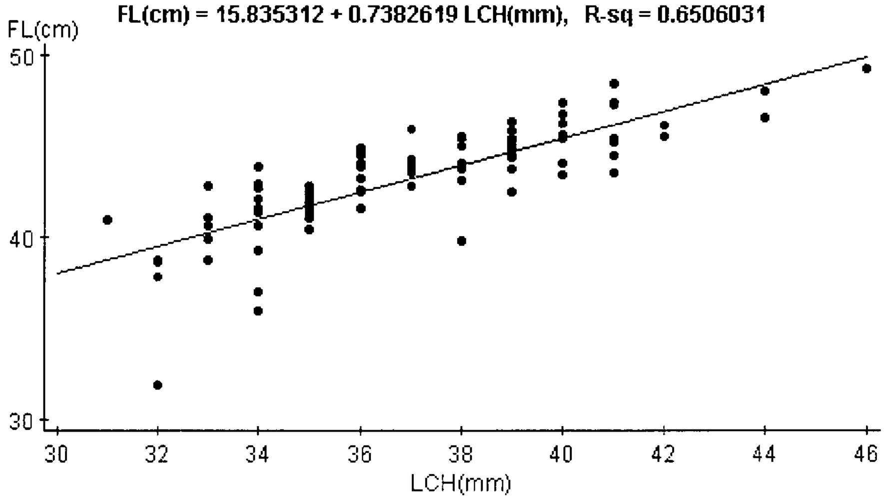
d)


FL(cm) = 17.104696 + 0.6180898 VDH(mm), R-sq = 0.42002597
FL(cm)
50
40
30
30
40
50
60
VDH(mm)

e)


FL(cm) = 17.079262 + 0.2837277 VHA(mm), R-sq = 0.7023568
FL(cm)
50
40
30
70
80
90
100
110
120
VHA(mm)

f)


FL(cm) = 15.835312 + 0.7382619 LCH(mm), R-sq = 0.6506031
FL(cm)
50
40
30
30
32
34
36
38
40
42
44
46
LCH(mm)

3.7.1.4 SIMPLE LINEAR REGRESSION EQUATIONS FOR ESTIMATING FEMUR LENGTH FROM SEGMENT MEASUREMENTS IN SOUTH AFRICAN BLACK FEMALES

Femoral length is regressed on each of the six fragment measurements in the Black females and the regression constants are presented in Table 28. The table includes slopes (with standard errors), intercepts (with standard errors), coefficients of determination, significances of the coefficient of regression, and standard errors of estimates. Based on this table, the linear relationship between length of femur (cm) and each segment measurement could be formulated in the form of a straight line equation (y = a + b x), with slope 'b' and intercept 'a'.

Therefore, the six straight line equations to predict femur length (cm) from each segment for South African Black females are presented as follows:

1) Using neck-shaft angle:
FL cm = 29.33 + 0.11 (NSA°) ± 2.07

2) Using neck length:
FL cm = 33.73 + 0.33 (NL mm) ± 1.65

3) Using intertrochanteric apical axis length:
FL cm = 21.62 + 0.38 (ITAAL mm) ± 1.40

4) Using vertical diameter of femur head:
FL cm = 18.42 + 0.60 (VDH mm) ± 1.66

5) Using upper breadth of the femur:
FL cm = 18.27 + 0.28 (VHA mm) ± 1.57

6) Using lateral condyle height:
FL cm = 21.91 + 0.61 (LCH mm) ± 1.52

In this case 'y' represents the femoral length which is the outcome variable and 'x' stands for each segment measurement, which is the predictor variable. This linear relation between femoral length and the other segment measurements in South African Black females is presented in Fig. 6.

TABLE 28: REGRESSION CONSTANTS FOR ESTIMATING FEMUR LENGTH IN CENTIMETRES, FROM VARIOUS FEMUR FRAGMENTS IN SOUTH AFRICAN BLACK FEMALES (n = 100)

SEGMENT	b[a]	S.E. (b)	A[b]	S.E. (a)	r^2[c]	t[d]	S.E.E.[e]
NSA°	0.11	0.04	29.33	4.94	0.07	2.69 (p<0.01)	2.07
NL mm	0.33	0.04	33.73	1.10	0.41	8.19 (p<0.0001)	1.65
ITAAL mm	0.38	0.03	21.62	1.83	0.57	11.47 (p<0.0001)	1.40
VDH mm	0.60	0.07	18.42	2.99	0.40	8.11 (p<0.0001)	1.66
VHA mm	0.28	0.03	18.27	2.66	0.46	9.17 (p<0.0001)	1.57
LCH mm	0.61	0.06	21.91	2.13	0.49	9.75 (p<0.0001)	1.52

[a] = Coefficient of regression (slope)

[b] = Intercept

[c] = Square of coefficient of correlation called coefficient of determination

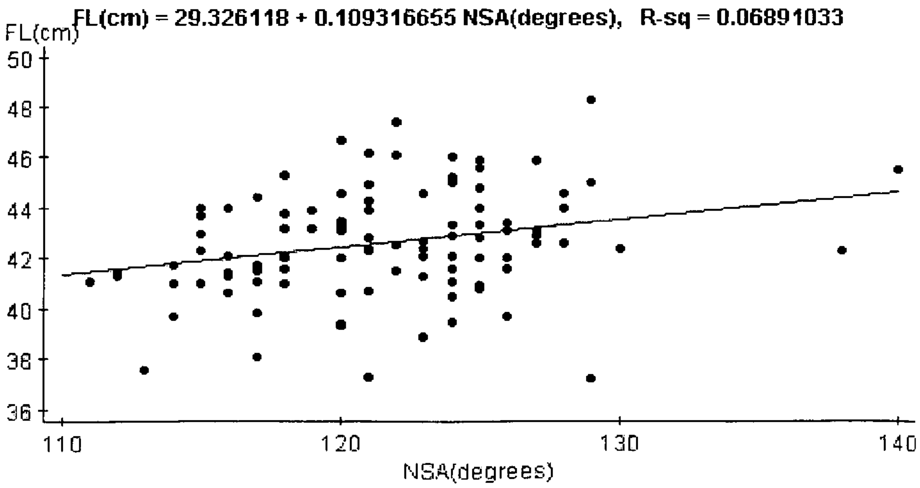
[d] = Significance of b

[e] = Standard error of estimate

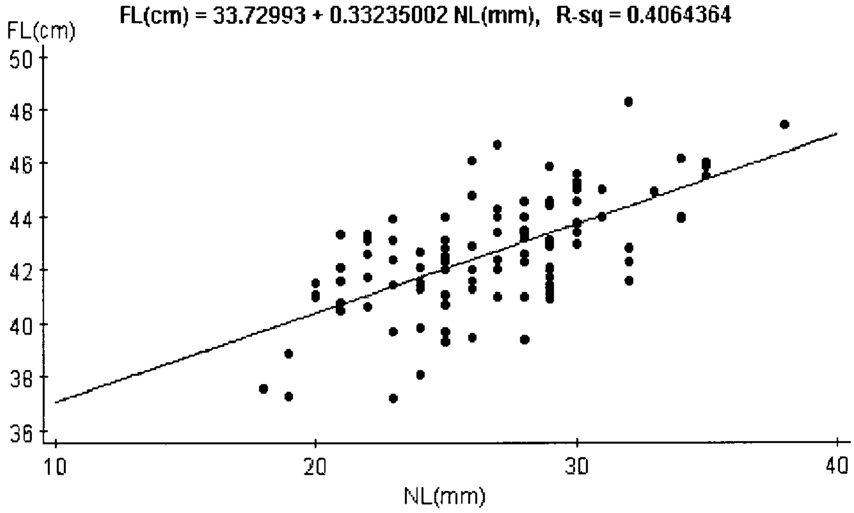
FIGURE 6(a-f):SCATTER PLOTS AND REGRESSION LINES OF FEMORAL LENGTH (ORDINATE) AGAINST EACH SEGMENT MEASUREMENT (ABSCISSA) FOR SOUTH AFRICAN BLACK FEMALES

8

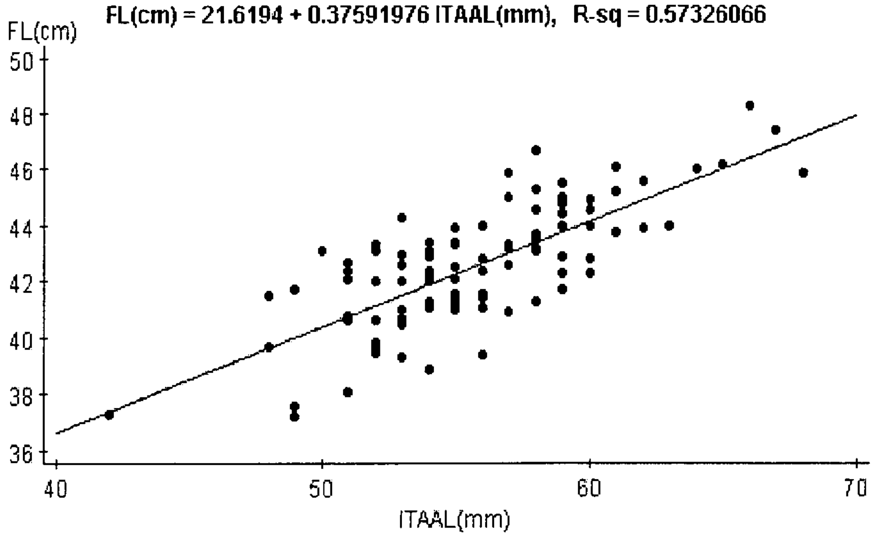
a)



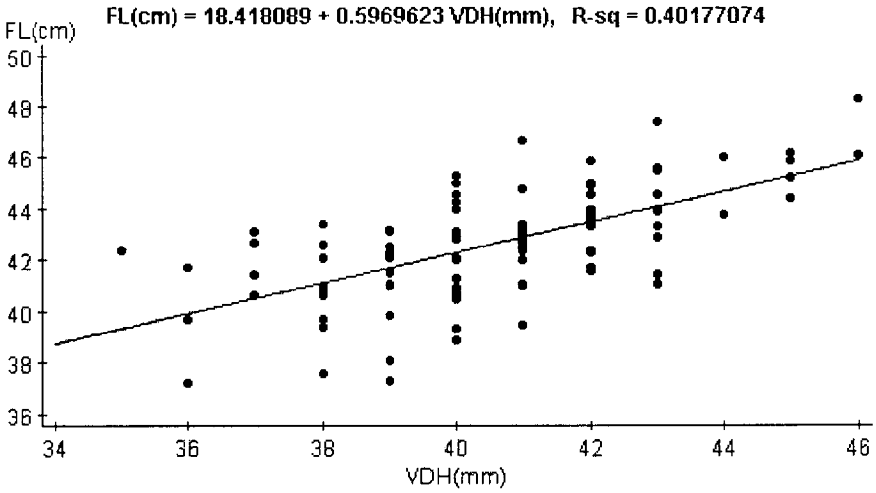
b)


FL(cm) = 33.72993 + 0.33235002 NL(mm), R-sq = 0.4064364
FL(cm)
50
48
46
44
42
40
38
36
10
20
30
40
NL(mm)

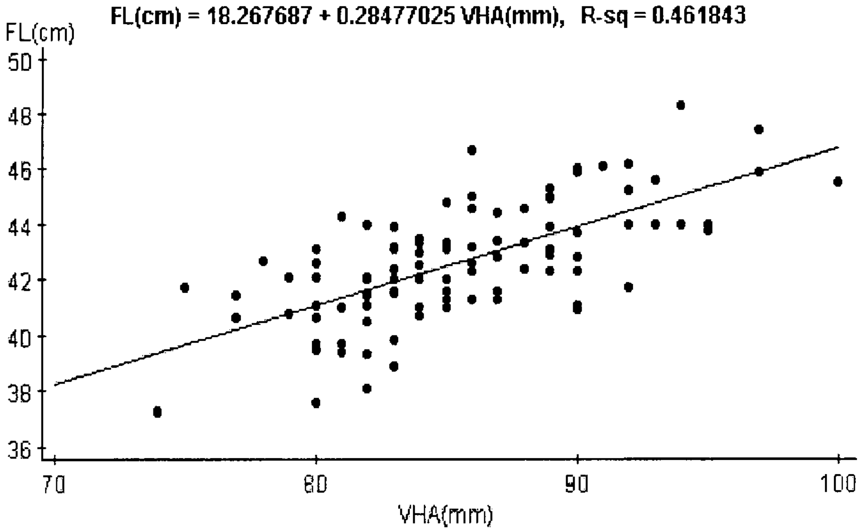
c)


FL(cm) = 21.6194 + 0.37591976 ITAAL(mm), R-sq = 0.57326066
FL(cm)
50
48
46
44
42
40
38
36
40
50
60
70
ITAAL(mm)

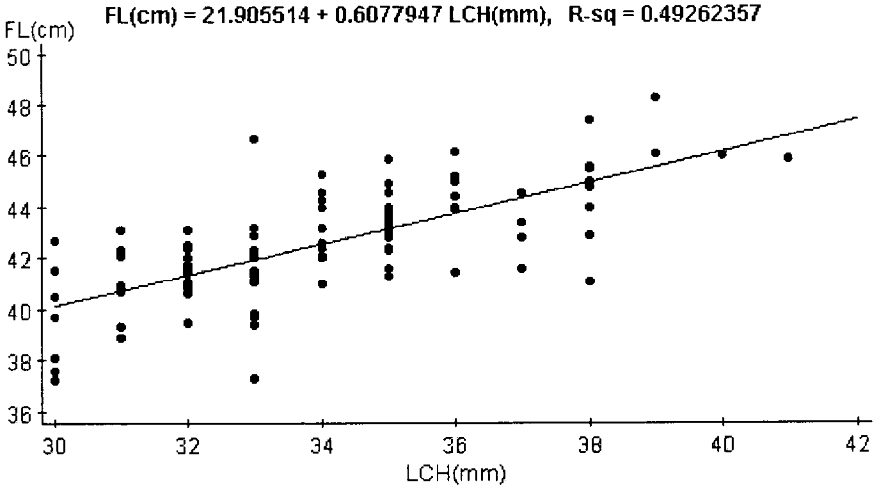
d)


FL(cm) = 18.418089 + 0.5969623 VDH(mm), R-sq = 0.40177074
FL(cm)
50
48
46
44
42
40
38
36
34
36
38
40
42
44
46
VDH(mm)

e)


FL(cm) = 18.267687 + 0.28477025 VHA(mm), R-sq = 0.461843
FL(cm)
50
48
46
44
42
40
38
36
70
80
90
100
VHA(mm)

f)



3.7.1.5 SIMPLE LINEAR REGRESSION EQUATIONS FOR ESTIMATING FEMUR LENGTH FROM SEGMENT MEASUREMENTS IN THE TOTAL SAMPLE

Here, the total sample (n = 400) is treated without consideration of race and sex. Femur length is regressed on each of the six segments and the regression constants are presented in Table 29. The table includes slopes (with standard errors), intercepts (with standard errors), coefficients of determination, significances of the coefficients of regression, and the standard errors of estimates. A straight line equation of the form y = a + b x could be presented which represents the linear relationship between FL cm (y) and each segment (x) while 'b' and 'a' represent the slope and the intercept of the equation.

TABLE 29: REGRESSION CONSTANTS FOR ESTIMATING FEMUR LENGTH IN CENTIMETRES, FROM VARIOUS FEMUR FRAGMENTS IN THE TOTAL SAMPLE (n = 400)

SEGMENT	b [a]	S.E. (b)	A [b]	S.E. (a)	r [2c]	t [d]	S.E.E. [e]
NSA°	0.32	0.02	5.25	2.13	0.46	18.36 ($p<0.0001$)	2.21
NL mm	0.45	0.01	30.24	0.46	0.71	30.92 ($p<0.0001$)	1.63
ITAAL mm	0.34	0.01	23.06	0.78	0.65	27.32 ($p<0.0001$)	1.77
VDH mm	0.57	0.02	19.39	1.08	0.58	23.28 ($p<0.0001$)	1.95
VHA mm	0.27	0.01	18.75	0.83	0.71	31.17 ($p<0.0001$)	1.62
LCH mm	0.59	0.02	21.77	0.76	0.69	29.74 ($p<0.0001$)	1.67

[a] = Coefficient of regression (slope)
[b] = Intercept
[c] = Square of coefficient of correlation called coefficient of determination
[d] = Significance of b
[e] = Standard error of estimate

Therefore, the following six straight line equations are derived for estimating femur length from each segment for the total sample without consideration of race and sex.

1) Using neck-shaft angle:
FL cm = 5.25 + 0.32 (NSA°) ± 2.21

2) Using neck length:
FL cm = 30.24 + 0.45 (NL mm) ± 1.63

3) Using intertrochanteric apical axis length:
FL cm = 23.06 + 0.34 (ITAAL mm) ± 1.77

4) Using vertical diameter of femur head:
FL cm = 19.39 + 0.57 (VDH mm) ± 1.95

5) Using upper breadth of the femur:
FL cm = 18.75 + 0.27 (VHA mm) ± 1.62

6) Using lateral condyle height:
FL cm = 21.77 + 0.59 (LCH mm) ± 1.67

3.7.2 COMPARISON OF REGRESSION MODELS OF THE PRESENT STUDY WITH THOSE OF OTHER STUDIES

Table 30 presents regression constants by Simmons *et al.* (1990) for upper breadth of femur (VHA), lateral condyle height (LCH), and vertical head diameter (VHD). The table is presented here for comparison with the present study. The comparison is principally based on the standard error of estimate. For comparable segments, the standard errors of estimate provided by this study are uniformly lower than those of Simmons *et al.* (1990). This indicates that the femoral length estimates in this study are more accurate for the study population. The only exception is the vertical head diameter in the regression equation for White females. The standard error of estimate in the regression equation of South African White females is 2.10, while in the case of the American White females it is 2.06.

TABLE 30: REGRESSION CONSTANTS FOR AMERICAN WHITES AND BLACKS AFTER SIMMONS *et al.* (1990)

	HEIGHT			FEMUR LENGTH		
	SLOPE	INTERCEPT	S.E.	SLOPE	INTERCEPT	S.E.
			PREDICTOR VARIABLE: VHA			
White males	0.78	89.64	6.10	0.29	14.81	2.10
White females	0.73	91.54	6.67	0.21	21.50	2.10
Black males	0.79	91.70	6.60	0.32	13.64	2.30
Black females	0.59	107.10	6.00	0.25	21.90	2.04
			PREDICTOR VARIABLE: LCH			
White males	1.47	107.09	6.24	0.54	20.86	2.18
White females	1.34	113.23	6.91	0.46	25.44	2.59
Black males	1.94	86.10	5.77	0.42	24.96	2.09
Black females	1.59	100.07	5.47	0.56	20.80	2.03
			PREDICTOR VARIABLE: VHD			
White males	1.11	113.89	6.77	0.43	23.57	2.32
White females	1.51	97.82	6.92	0.54	19.45	2.56
Black males	1.35	99.22	7.16	0.47	20.22	2.06
Black females	1.59	92.43	5.59	0.58	17.12	1.99

To determine how the equations presented in this study compare with those derived from American samples, the mean segment measurements for South African groups are used. Each mean segment measurement is inserted first into the equations derived in the present study and then into the equations by Simmons *et al.* (1990) in order to compare for the estimated femur length based on each equation. This allows comparison of the estimated value of femur length from the two different equations using the same value of a predictor variable.

Table 31 compares the equations by Simmons *et al.* (1990) with the present for comparable segments in the South African and American White males. Table 31 illustrates that in all cases, the estimated femur lengths using Simmons' *et al.* (1990) formulae are smaller than when the femur lengths are estimated using the equations derived from the South African White male sample. The difference observed between the results of the two sets of equations range from a low value of 1.96 cm for upper breadth of the femur to an upper value of 2.95 cm for lateral condyle height. With the present formulae, the estimated lengths of femur range from 46.51 cm for the vertical head diameter to 46.73 cm for upper breadth of the femur, the total range being 0.22 cm. On the basis of Simmons' *et al.* (1990) formulae for American Whites, the estimated femur lengths range from a low value of 43.76 cm for lateral condyle height to 44.77 cm for upper breadth of femur, the total range being 1.01 cm. The equations derived from the South African White male sample provide less variation in estimated femoral length among the various segments than do the American formulae. This is reflected in the smaller ranges observed in the South African White male equations.

TABLE 31: COMPARISON OF ESTIMATED FEMUR LENGTH IN SOUTH AFRICAN WHITE MALES, USING REGRESSION FORMULAE BY SIMMONS *et al.* FOR AMERICAN WHITE MALES AND THE REGRESSION FORMULAE DERIVED FOR THE SOUTH AFRICAN WHITE MALES IN THE PRESENT STUDY (n = 100)

SEGMENT	MEAN (mm)*	ESTIMATED FL AND RANGES (cm)**	
		PRESENT STUDY	SIMMONS *et al.* (1990)
VHA	103.3	46.73 (45.17 - 48.29)	44.77 (42.67 - 46.87)
LCH	42.4	46.71 (45.17 - 48.25)	43.76 (41.58 - 45.94)
VHD	48.5	46.51 (44.42 - 48.60)	44.43 (42.11 - 46.75)

* = Means for South African White male

** = Ranges are based upon the standard error for each equation

Table 32 presents comparison of the equations by Simmons *et al.* (1990) with the present for comparable segments in the American and South African Black males. The table shows that in all cases, the estimated femur lengths using formulae by Simmons *et al.* (1990) are smaller than when the femur lengths are estimated using the equations derived from the South African Black male sample. The differences observed between the results of the two sets of equations range from a low value of 0.57 cm for upper breadth of femur to an upper value of 1.34 cm for lateral condyle height. With the present formulae the estimated lengths of femur range from 44.65 cm for maximum vertical diameter of femur head to 44.83 cm for upper breadth of femur, the total range being 0.18 cm. Based on the formulae by Simmons *et al.* (1990) for American Blacks, the estimated lengths of femur range from a low value of 43.43 cm for lateral condyle height to 44.26 for upper breadth of femur, the total range being 0.83 cm. The equations derived from the South African Black male sample provide less variation in estimated length of femur among the various segments than do the American formulae by Simmons *et al.* (1990). This is reflected in the smaller ranges observed in the South African Black Male equations.

TABLE 32: COMPARISON OF ESTIMATED FEMUR LENGTH IN SOUTH AFRICAN BLACK MALES, USING REGRESSION FORMULAE BY SIMMONS *et al.* FOR AMERICAN BLACK MALES AND THE REGRESSION FORMULAE DERIVED FOR THE SOUTH AFRICAN BLACK MALES IN THE PRESENT STUDY (n = 100)

SEGMENT	MEAN (mm)*	ESTIMATED FL AND RANGES (cm)**	
		PRESENT STUDY	SIMMONS *et al.* (1990)
VHA	95.7	44.83 (43.24 – 46.42)	44.26 (41.96 - 46.56)
LCH	39.1	44.77 (43.07 – 46.47)	43.43 (40.84 – 46.02)
VHD	45.0	44.65 (42.70 – 46.60)	43.75 (41.19 - 46.31)

* = Means for South African Black male

** = Ranges are based upon the standard error for each equation

Table 33 presents comparison of the equations by Simmons *et al.* (1990) with the present for comparable segments in the American and South African White females. In all cases, the estimated femur lengths using formulae by Simmons *et al.* (1990) are uniformly smaller than when the femoral lengths are estimated using the equations derived from the South African White female sample. The differences observed between the two sets of equations range from a low value of 2.01 cm for upper breadth of femur to an upper value of 3.19 cm for vertical diameter of femoral head. With the present formulae the estimated lengths of femur range from 42.81 cm for upper breadth of femur to 43.21 cm for lateral condyle height, the total range being 0.4 cm. On the basis of the formulae by Simmons *et al.* (1990) for American White females, the estimated femur lengths range from 40.01 cm for vertical diameter of femoral head to 40.80 cm for upper breadth of the femur, the total range being 0.79 cm. Once more, the equations derived from the South African White female sample provide less variation in femur length among the various segments than do the American formulae. This is clearly demonstrated in the smaller ranges observed in the South African White female equations.

TABLE 33: COMPARISON OF ESTIMATED FEMUR LENGTH IN SOUTH AFRICAN WHITE FEMALES, USING REGRESSION FORMULAE BY SIMMONS *et al.* FOR AMERICAN WHITE FEMALES AND THE REGRESSION FORMULAE DERIVED FOR THE SOUTH AFRICAN WHITE FEMALES IN THE PRESENT STUDY (n = 100)

SEGMENT	MEAN (mm)*	ESTIMATED FL AND RANGES (cm)**	
		PRESENT STUDY	SIMMONS *et al.* (1990)
VHA	91.9	42.81 (41.31 – 44.31)	40.80 (38.70 – 42.90)
LCH	37.0	43.21 (41.58 – 44.84)	40.50 (38.41 – 42.59)
VHD	42.1	43.20 (41.10 – 45.30)	40.01 (37.95 – 42.07)

* = Means for South African White female

** = Ranges are based upon the standard error for each equation

Table 34 presents comparison of the equations by Simmons *et al.* (1990) with the present for comparable segments in the American and South African Black females. The table indicates that in two of the three cases, the estimated femur lengths using formulae by Simmons *et al.* (1990) are smaller than when the femur lengths are estimated using the equations derived from the South African Black female sample. In one case for upper breadth of femur, the estimated femur length using formulae by Simmons *et al.* (1990) is greater than when the femur length is estimated using the equation derived from the South African Black female sample. The femur length for upper breadth of the femur using Simmons *et al.* (1990) formula is 43.23 cm and it is 42.21 cm using the equation derived from the South African Black female sample. The difference observed between the results of the two sets of equations range from a low value of 1.02 cm for upper breadth of femur to an upper value of 2.81 cm for lateral condyle height. With the present formulae the estimated lengths of femur range from 42.21 cm for upper breadth of femur to 42.72 cm for vertical diameter of femoral head, the total range being 0.51 cm only. Based on the formulae for American Black females by Simmons *et al.* (1990), the estimated lengths of femur range from 39.90 cm for lateral condyle height to 43.23 cm fro upper breadth of femur, the total range being 3.33 cm. The equations derived from the South African Black female sample provide less variation in estimated femoral length among the various segments than do the American formulae. This is reflected in the considerably smaller ranges observed in the South African Black female equations.

TABLE 34: COMPARISON OF ESTIMATED FEMUR LENGTH IN SOUTH AFRICAN BLACK FEMALES, USING REGRESSION FORMULAE BY SIMMONS *et al.* FOR AMERICAN BLACK FEMALES AND THE REGRESSION FORMULAE DERIVED FOR THE SOUTH AFRICAN BLACK FEMALES IN THE PRESENT STUDY (n = 100)

SEGMENT	MEAN (mm)*	ESTIMATED FL AND RANGES (cm)**	
		PRESENT STUDY	SIMMONS *et al.* (1990)
VHA	85.5	42.21 (40.64 – 43.78)	43.23 (41.19 – 45.27)
LCH	34.1	42.71 (41.19 – 44.23)	39.90 (37.87 – 41.93)
VHD	40.5	42.72 (41.06 – 44.38)	40.61 (38.62 – 42.60)

* = Means for South African Black female

** = Ranges are based upon the standard error for each equation

Table 35 presents regression constants by Prasad *et al.* (1996) of the total sample for neck-shaft angle, neck length, intertrochanteric apical axis length, and vertical diameter of head of femur. This table is presented for comparison with the total sample of the present. The comparison is based primarily on the standard error of estimate and coefficient of determination (r^2). For comparable segments, the standard errors of estimate provided by the present study are uniformly lower than those of Prasad *et al.* (1996). Moreover, the coefficients of determination provided by the present study are uniformly higher than those of Prasad *et al.* (1996). These indicate that the regression equations for estimating femur length using the given fragments in this study are more accurate for the study population.

TABLE 35: REGRESSION CONSTANTS FOR SOUTHERN INDIA SUBJECTS AFTER PRASAD *et al.* (1996)

Y	X		b[a]	S.E. (b)	a[b] intercept	S.E. (a)	r^2[c]	t[d]	S.E.E.[e]
FL	NSA	Male	2.15	0.73	176.13	92.79	0.09	2.9**	21.667
		Female	1.70	0.68	203.08	86.28	0.07	2.5*	23.149
		Left	2.51	0.74	116.71	93.41	0.12	3.4***	22.715
		Right	1.67	0.95	223.05	119.60	0.04	1.8 NS	30.990
		TOTAL	**2.07**	**0.60**	**172.73**	**75.66**	**0.06**	**3.4*** **	**26.926**
	NL	Male	1.49	0.54	404.06	16.44	0.08	2.7**	21.791
		Female	2.40	0.63	354.27	16.87	0.16	3.8***	22.053
		Left	3.12	0.49	347.62	14.09	0.32	6.3***	20.025
		Right	2.85	0.69	352.43	20.08	0.17	4.1***	28.719
		TOTAL	**2.97**	**0.42**	**350.55**	**12.14**	**0.23**	**7.0*** **	**24.523**
	ITAAL	Male	1.39	0.37	364.79	22.43	0.13	3.7***	21.100
		Female	0.96	0.42	365.34	23.24	0.06	2.2*	23.299
		Left	1.28	0.39	362.36	22.34	0.11	3.2**	22.815
		Right	2.56	0.40	283.86	23.47	0.34	6.4***	25.673
		TOTAL	**1.94**	**0.28**	**322.29**	**16.29**	**0.22**	**6.9*** **	**24.575**
	VDH	Male	2.24	0.57	352.28	24.56	0.14	3.8***	20.962
		Female	3.08	1.00	297.17	39.28	0.11	3.1**	22.697
		Left	4.00	0.65	270.19	26.81	0.31	6.2***	20.143
		Right	3.79	0.68	278.02	28.35	0.27	5.5***	26.901
		TOTAL	**3.87**	**0.47**	**275.13**	**19.44**	**0.29**	**8.2*** **	**23.533**

[a] = Coefficient of regression
[b] = Intercept, a constant
[c] = Square of coefficient of correlation known as coefficient of determination
[d] = Significance of *b*
[c] = Standard error of estimate
* = *P*<0.05; ** = *P*<0.01; *** = *P*<0.001
NS = Non-significant

Table 36 compares the equations by Prasad *et al.* (1996) with the present for comparable segments in the totals of South African and South Indian samples. To determine how the equations presented in this study compare with those derived from South Indian samples, the mean segment measurements in the total of the present study are used. The table indicates that the estimated femur lengths using formulae by Prasad *et al.* (1996) are smaller than when the femur lengths are estimated during the equations derived from the South African total sample. The only exception is for vertical diameter of head in which case the femur length estimate using the equation by Prasad *et al.* (1996) is greater than when it is computed using the present formula. The differences observed between the results of the two sets of equations range from a low value of 0.01 cm for neck length to an upper value of 1.38 cm for neck-shaft angle. In general, the femur length estimates are close for NL, ITAAL, and VDH in the two sets of equations. However, the ranges are quite wider when femur length is estimated using the regression formulae by Prasad *et al.* (1996) than when it is calculated using the regression formulae of the present. With the present formulae, the estimated lengths of femur range from 44.23 cm for the neck-shaft angle to 44.51 for ITAAL, the total range being 0.28 cm. Based on the formulae by Prasad *et al.* (1996) for South Indian subjects, the estimated femur lengths range from a lower value of 42.85 cm for NSA to an upper value of 44.53 cm for vertical diameter of head of femur, the total range being 1.68 cm. Thus, the equations derived from the South African total sample provide less variation in estimated femur length among the various segments than do the formulae by Prasad *et al.* (1996) for the total of South Indian sample. This is clearly reflected in the smaller ranges observed in the equations of the present.

From the foregoing discussions, one could easily see that the present study provides regression formulae with lower standard errors of estimate and higher coefficients of determination than when compared with comparable segments of Simmons *et al.* (1990) and Prasad *et al.* (1996). In addition the formulae derived by these authors, when applied to the present sample, give lower estimates of femur length repeatedly with greater variability. Therefore, the regression formulae derived by the present study provide higher degrees of prediction to compute femur length from its fragments for South African Blacks and Whites.

TABLE 36: COMPARISON OF ESTIMATED FEMUR LENGTH IN THE TOTAL SOUTH AFRICAN SAMPLE, USING REGRESSION FORMULAE BY PRASAD *et al.* FOR THE TOTAL SOUTH INDIAN SAMPLE AND THE REGRESSION FORMULAE DERIVED FOR THE TOTAL SOUTH AFRICAN SAMPLE IN THE PRESENT STUDY (n = 400)

SEGMENT	MEAN (mm)*	ESTIMATED FL AND RANGES (cm)**	
		PRESENT STUDY	SIMMONS *et al.* (1999)
NSA	121.8	44.23 (42.02 – 46.44)	42.85 (40.16 – 5.54)
NL	31.5	44.42 (42.79 - 46.05)	44.41 (41.96- 46.86)
ITAAL	63.1	44.51 (42.74 – 46.28)	44.22 (41.76 – 46.68)
VDH	44.0	44.47 (42.52 – 46.42)	44.53 (42.18 – 46.88)

* = Means for the total South African sample

** = Ranges are based upon the standard error for each equation

3.7.3. MULTIPLE LINEAR REGRESSION EQUATIONS

In this section, an attempt is made to examine the dependency of femur length on a combination of several variables, not just one. The joint influence of the variables, taking account of possible correlations among them, is investigated using multiple linear regression models for each race and sex. Stepwise selection procedure of the SAS package was employed to arrive at the best combination of variables with the highest predictive capability (with $p < 0.15$ to enter and $p > 0.15$ to remove). Accordingly, multiple linear regression models of the form $y = a + b_1 x_1 + b_2 x_2 + b_3 x_3 \dots + b_n x_n$ were derived for each race and sex, where 'y' is the dependent variable (FL cm), 'a' is the intercept, b_1, b_2, b_3, ... and b_n are partial regression coefficients, and x_1, x_2, x_3, ... x_n are the explanatory variables (the various segment measurements).

3.7.3.1. MULTIPLE LINEAR REGRESSION MODEL FOR SOUTH AFRICAN WHITE MALES

Multiple regression constants for estimating femur length in centimetres in South African White males are presented in Table 37. The table includes the intercept (with S.E.), partial coefficients of regression (with their standard error), and the significances of each coefficient. Using the stepwise selection procedure, the segments left for inclusion in the multiple regression model for South African White males are NSA, NL, and LCH. All variables left in the model are significant at the 0.15 levels. No other variable met the 0.15 significance levels for entry into the model. The coefficient of determination for the equation (R-square) is 0.85 and the standard error of the estimate (S.E.E.) is 1.01.

TABLE 37: CONSTANTS OF MULTIPLE REGRESSION FOR ESTIMATING FEMUR LENGTH IN CENTIMETERES, BY A COMBINATION OF NSA°, NL mm, AND LCH mm FOR SOUTH AFRICAN WHITE MALES (n = 100)
(Model R-square = 0.85; S.E.E. = 1.01)

SEGMENT	PARAMETER ESTIMATE	STANDARD ERROR	F VALUE	p<
INTERCEPT	102.94	22.33	21.25	0.0001
NSA°	1.50	0.25	37.09	0.0001
NL mm	2.22	0.40	31.47	0.0001
LCH mm	2.27	0.54	17.42	0.0001

Thus, the equation of multiple regression using NSA, NL, and LCH for South African White males is:

$$\text{FL cm} = 102.94 + 1.50\,(\text{NSA}^\circ) + 2.22\,(\text{NL mm}) + 2.27\,(\text{LCH mm}) \pm 1.01.$$

3.7.3.2 MULTIPLE LINEAR REGRESSION MODEL FOR SOUTH AFRICAN BLACK MALES

Table 38 presents constants of multiple regression for South African Black males. The table includes the intercept (with standard error), partial coefficients of regression (with standard errors), and the significances of each coefficient. Using stepwise selection procedure, five out of six segment measurements were left for entry into the multiple regression model for South African Black males. These are NSA°, NL, VDH, VHA, and LCH. All these variables were significant at the 0.15 level for entry into the model. The only variable that was removed from the model was ITAAL, because it did not meet the 0.18 significance levels for entry into the model. The coefficient of determination (R-square) for the equation is 0.77 and the standard error of the estimate (S.E.E.) is 1.30.

Therefore, the equation of multiple regression for South African Black males using the variables, left for entry into the model is as follows:

$$\text{FL cm} = 91.10 + 0.73\,(\text{NSA}^\circ) + 1.81\,(\text{NL mm}) + 1.61\,(\text{VDH mm}) + 0.73\,(\text{VHA mm}) + 1.77\,(\text{LCH mm}) \pm 1.30.$$

TABLE 38: CONSTANTS OF MULTIPLE REGRESSION FOR ESTIMATING FEMUR LENGTH IN CENTIMETERES, BY A COMBINATION OF NSA°, NL mm, VDH mm, VHA mm, AND LCH mm FOR SOUTH AFRICAN BLACK MALES (n = 100)
(Model R-square = 0.77; S.E.E. = 1.30)

SEGMENT	PARAMETER ESTIMATE	STANDARD ERROR	F VALUE	p<
INTERCEPT	91.10	38.42	5.62	0.05
NSA°	0.73	0.31	5.59	0.05
NL mm	1.81	0.47	14.58	0.001
VDH mm	1.61	0.68	5.57	0.05
VHA mm	0.73	0.41	3.10	0.1
LCH mm	1.77	0.69	6.60	0.05

3.7.3.3 MULTIPLE LINEAR REGRESSION MODEL FOR SOUTH AFRICAN WHITE FEMALES

Constants of multiple regression for South African White females are presented in Table 39. The table shows the intercept (with standard error), partial coefficients of regression (with standard errors), and the significances of each coefficient. Employing the stepwise selection procedure, the only variables left for entry into the model were NSA and VHA. These two are significant at the 0.15 level. All the rest (NL, ITAAL, VDH, and LCH) did not meet the 0.15 significance level and are removed from the model. The coefficient of determination (R-square) for the model is 0.83 and the standard error of the estimate (S.E.E.) is 1.14.

The equation of multiple regression for South African White females using the selected variables, is:

FL cm = 56.18 + 2.31 (NSA°) + 1.07 (VHA mm) ± 1.14.

TABLE 39: CONSTANTS OF MULTIPLE REGRESSION FOR ESTIMATING FEMUR LENGTH IN CENTIMETERES, BY A COMBINATION OF NSA° AND VHA mm FOR SOUTH AFRICAN WHITE FEMALES (n = 100)
(Model R-square = 0.83; S.E.E. = 1.14)

SEGMENT	PARAMETER ESTIMATE	STANDARD ERROR	F VALUE	p<
INTERCEPT	56.18	18.72	9.00	0.01
NSA°	2.31	0.27	73.05	0.0001
VHA mm	1.07	0.25	18.38	0.0001

3.7.3.4 MULTIPLE LINEAR REGRESSION MODEL FOR SOUTH AFRICAN BLACK FEMALES

Table 40 presents the constants of multiple regression for South African Black females. The table includes the intercept (with its standard error), partial coefficients of regression (with standard errors), and the significances of each coefficient. Using the stepwise selection procedure of SAS, variables that met the 0.15 significance level and left for entry into the model are NL, ITAAL, and LCH. The other three variables (NSA, VDH, and VHA) were removed from the model since they did not meet the 0.15 significance level for entry into the equation. The coefficient of determination (R-square) for the model is 0.64 and the standard error of the estimate (S.E.E.) is 1.30.

Therefore, the equation of multiple regression for South African Black females using the segments left for entry, is as follows:

$$\text{FL cm} = 194.27 + 0.89\,(\text{NLmm}) + 1.88\,(\text{ITAALmm}) + 3.03\,(\text{LCHmm}) \pm 1.30.$$

TABLE 40: CONSTANTS OF MULTIPLE REGRESSION FOR ESTIMATING FEMUR LENGTH IN CENTIMETERES, BY A COMBINATION OF NLmm, ITAALmm, AND LCHmm FOR SOUTH AFRICAN BLACK FEMALES (n = 100) (Model R-square = 0.64; S.E.E. = 1.30)

SEGMENT	PARAMETER ESTIMATE	STANDARD ERROR	F VALUE	p<
INTERCEPT	194.27	20.07	93.74	0.0001
NL mm	0.89	0.50	3.15	0.1
ITAAL mm	1.88	0.59	10.25	0.01
LCH mm	3.03	0.75	16.22	0.0001

It is evident that in all the multiple linear regression functions formulated the coefficients of determination (r^2) are Very high and the standard errors of the estimates (S.E.E.) are very low. This indicates that the models developed are robust and the accuracy of prediction by the regression functions for the study population is very high.

CHAPTER 4: SUMMARY AND CONCLUSION

KEY WORDS: Physical anthropology; Human identification; Bone length; Stature estimation; Femur; Fragmentary measure; Regression; Proximal end; Distal end.

It is commonly accepted that standards for skeletal identification vary among different populations, and that the standards for one population may not be applied for another population. Therefore, it is necessary to provide standards for the identification of different traits on specific population groups based on data obtained from a uniform source. Another factor that may necessitate constant revision of standards is the possible occurrence of temporal change in a population. The present study provides formulae for the estimation of femur length from fragmentary remains in South African Whites and Blacks using data obtained from the same population source. These data are from South African Whites and Blacks of both sexes from the Raymond Dart Skeletal Collection housed at the Department of Anatomical Sciences, University of Witwatersrand, Johannesburg.

Only subjects with known race and sex were included. The age range of the sample is between 20 and 89 years. Maximum length of femur (FL), neck-shaft angle (NSA), neck length (NL), maximum vertical diameter of the head of femur (VDH), intertrochanteric apical axis length (ITAAL), upper breadth of femur (VHA), and lateral condyle height (LCH) were measured for each subject. These parameters of the femur are defined and measured using well defined anatomical landmarks and standard techniques. For maximum femur length, the average of a pair was utilized in the statistics because of greater reliability of an average. When the bone of only one side is available, an adjustment in an equation based on the average is not necessary as there is no significant difference in length between the bones of the two sides. To minimize intra observer variation, all measurements were taken twice and the average was recorded. The data were analyzed using various procedures of a PC version of SAS software program. The statistical analysis comprised of descriptive statistics, Student's t-test, correlation analysis, and regression analysis.

Each variable has been described in terms of the mean, standard deviation, median, and range for each race and sex as well as the total sample.

When the two sexes within a race are compared, males have significantly longer femora. Likewise, all segment measurements are larger in males than in females of respective race. The only exception is the neck-shaft angle in the Black South Africans where there is no significant difference between the two sexes. South African Whites and Blacks of the same sex were also compared. The White males significantly exceed the Black males in all the measurements. The White and Black females do not have significant differences with respect to femur length and neck-shaft angle. Apart from this, the White females significantly exceed the Black females in the remaining five measurements. According to previous studies on American populations, the Blacks of both sexes have longer limb bones than the Whites. The results of this study are contrary to this: the Black males have significantly shorter femora than the White males and females of the two races do not have significant differences. This demonstrates population standards vary among various population groups and the need for population-specific formulae, tables and multiplication factors.

The mean femoral lengths of South African Blacks of both sexes are considerably shorter than those of American Blacks. Comparison of corresponding segments (VHA, VDH, LCH) from Simmons *et al.* (1990) for the Terry Collection subjects with the present indicated the following. One, the average measurement for all three segments (VHA, VDA, LCH) is smaller in Black South Africans of both sexes than the American Blacks of respective sex; two, the average measurement for all three variables are greater in South African White males than in American White males; three, South African White females exceed in two of the segments (VHA and LCH) from American White females.

The present sample was also compared with corresponding variables (NSA, NL, ITAAL, VDH, FL) with Tamil Nadu subjects of Southern India after Prasad *et al.* (1996).

The correlation analysis between femur length and the six segments indicated that all the segments on the proximal and distal ends of femur are significantly and positively correlated with femur length. This indicates the high predictive capability of these segments for estimating femur length. Comparison of correlation coefficients of corresponding segments (VHA, VDH, LCH) between the present and those by Simmons *et al.* (1990) showed that all correlation coefficients are higher in the former than the latter. Corresponding segments (NSA, NL, ITAAL, VDH, FL) were also compared between the present and those of Prasad *et al.* (1996). Correlation coefficients of the present were again uniformly higher in the present than those by Prasad *et al.* (1996).

The intercorrelation matrices for each race and sex showed that all six segments significantly correlate among each other in all groups. The only exception is in the Black females where neck-shaft angle did not correlate significantly with neck length, intertrochanteric apical axis length, and vertical diameter of head of femur.

Femur length was regressed on each segment measurement and on a combination of segments for each race and sex. As a result, the best fitting simple linear regression models of the form $y = a + bx$ based on the least squares method are developed for each race and sex.

Besides, multiple linear regression models of the form $y = a + b_1 x_1 + b_2 x_2 \ldots + b_n x_n$ are developed for each race and sex. The stepwise selection procedure of SAS is used to select the best combination of segments for estimating femur length with a higher degree of accuracy.

A total of 30 simple linear regression equations have been presented for estimating femur length from its fragments. Six equations are derived for each of the four groups studied (White males, Black males, White females, and Black females) and six are derived for the total sample without consideration of race and sex. In addition, four multiple regression equations (one for each of the four groups) have been developed. The equations, derived using 'b' and 'a' values, with higher coefficients of determination and lower standard errors of estimate are the equations of choice.

The regression equations formulated for reconstruction of femur length in the South African White males reveal that the coefficient of determination (r^2) varies between 0.36 and 0.74, and the standard errors of estimate range between 1.34 and 2.09. The best estimates of femur length are obtained from neck length ($r^2 = 0.74$), neck-shaft angle ($r^2 = 0.71$), lateral condyle height ($r^2 = 0.65$), and upper breadth of femur ($r^2 = 0.64$).

Based on the simple linear regression equations computed for Black males, the coefficient of determination (r^2) varies from 0.32 for the neck-shaft angle to 0.64 for neck length and upper breadth of femur. The best estimates of femur length are obtained from neck length ($r^2 = 0.64$), upper breadth of femur ($r^2 = 0.64$), and intertrochanteric apical axis length ($r^2 = 0.62$).

In White females, the best estimates of femur length are obtained from neck-shaft angle ($r^2 = 0.80$), upper breadth of femur ($r^2 = 0.70$), and neck length ($r^2 = 0.69$). The coefficient of determination in White females is sufficiently higher (between 0.42 for vertical diameter of the head of femur and 0.80 for neck-shaft angle).

In Black females, the coefficients of determination (r^2) are quite lower ranging from 0.07 to 0.57. The best estimates of femoral length are obtained from intertrochanteric apical axis length ($r^2 = 0.57$), lateral condyle height ($r^2 = 49$), and upper breadth of femur ($r^2 = 0.46$).

In order to enhance the accuracy in the prediction of femur length, the use of multilinear regression analysis has been employed.

In White males, a combination of three fragmentary measurements (NSA, NL, and LCH) proved to be the most effective in improving the accuracy of determination. The R-square increased to 0.85, as against the values of simple regression (Table 25).

In Black males, a combination of five segments (NSA, NL, VDH, VHA, and LCH) proved to be the most effective in improving the accuracy of determination of femur length. The R-square increased to 0.77, as compared to the values of simple regression (Table 26).

In White females, the combination of two variables which proved to be the most effective in improving the accuracy of prediction of femur length are neck-shaft angle and upper breadth of femur. The R-square increased to 0.83, as compared to the values of simple regression (Table 27). In White females NSA as a single variable has a predictive accuracy comparable to the multilinear equation formulated.

In Black females, three combinations of segments (NL, ITAAL, and LCH) proved to be the most effective in improving the accuracy of prediction of femur length. The R-square is raised to 0.64, as against the values of simple regression presented in Table 28.

Once the length of femur is determined, it can be used to estimate the stature of the individual by the available regression equations. The revised equations developed by Lundy (1983, 1987) are recommended for use in South African Blacks as these equations are specifically derived for this population group for estimation of stature from whole limb bones. The author used Fully's Anatomical Method on Skeletal Material of South African Blacks to derive formulae for use specifically in this population group.

This study has demonstrated that South African Whites differ metrically from American Whites in the various measurements of femur. Thus, it is recommended that there is a need to use regression formulae specifically developed for South African Whites to estimate stature from the whole length of femur and other long bones. Dayal *et al.* (2002) studied stature estimation from long bones in South African Whites and the models developed in the study can be specifically useful in South Africa.

Jantz and Moore-Jansen (1988) have shown that the Terry Collection differs from the contemporary White and Black population, with present-day populations exhibiting significantly longer fomora. Simmons *et al.* (1990) also showed that Terry Collection heights are considerably below Trotter and Gleser's (1958) Korean War dead and modern forensic science cases. For this reason, the use of the formulae to estimate maximum femur length may be more useful than those estimating stature directly due to this secular trend in stature increase.

In addition to the above noted secular trend for increased stature, difference in body proportions over several generations have been noted for Japanese medical students by Ohyama *et al.* (1987). They reported that while the mean standing height of the Japanese students increased over three decades (1960's to 1980's), the mean leg length for these individuals remained constant. This indicates another potential difficulty in applying formulae for stature estimation, which are derived from Terry Collection sample. Simmons *et al.* (1990) caution that modern forensic samples do not correlate precisely with earlier populations.

In this study, the equations are derived by the regression among FL and NSA, NL, ITAAL, VDH, VHA, as well as LCH. The factors that affect the FL in one population would have, correspondingly in proportion, affected the markers as well. This can eliminate the scope for bias.

Such estimation of femoral length and stature from the dimensions of the proximal and distal ends of femur has potential for application in physical anthropology, medical jurisprudence, and forensic identification of an individual.

The sample was restricted to South African Whites and Blacks. Therefore, until demonstrated otherwise, these equations should be considered population-specific. Further, despite a level of precision comparable to existing, better-established methods, the technique presented here is offered only as a supplement for these methods. Whenever possible, stature estimates should always be made using the most reliable technique on the most reliable element, that is, from intact bones. With these caveats stated, the proximal and distal ends of femur are useful for estimating femur length and stature in archaeological and forensic science cases where no intact elements are recovered.

This is strongly supported by an explanation for the statistical validity of the models presented in this study. Most of the models are significant at $p<0.0001$ level, r^2 values are >60% (particularly, r^2 values of the multiple regression models are greater than or close to 80%), standard errors of the regression coefficients as well as standard errors of estimates are very small. These statistics should guarantee that these models are robust. Therefore, the equations derived in this study offer physical anthropologists, forensic scientists, and archaeologists a reasonable degree of precision in estimating femur length and stature from proximal and distal segments of the femur for both sexes of South African Whites and Blacks.

OPSOMMING

VOORSPELLING VAN FEMORALE LENGTE DEUR GEBRUIK TE MAAK VAN MERKERS OP DIE PROKSIMALE EN DISTALE PUNTE DAARVAN

SLEUTELWOORDE: Fisiese antropologie; Menslike indentifisering; Beenlengte; Lengteskatting; Femur; Meting van beenfragmente; Regressie; Proksimale punt; Distale punt.

Dit word algemeen aanvaar dat standaarde vir skeletale identifisering tussen die onderskeie bevolkingsgroepe verskil en dat die standaarde vir een bevolkingsgroep nie op dié van 'n ander van toepassing is nie. Daarom is dit nodig om standaarde te bepaal vir die identifisering van verskeie menslike eienskappe op bepaalde bevolkingsgroepe, wat op data vanaf 'n eenvormige bron verkry is. 'n Ander faktor wat voortdurende hersiening van standaarde mag noodsaak is die moontlike voorkoms van temporale verandering in 'n bevolking. Die huidige studie stel formules daar vir die skatting van femurlengte van gefragmenteerde oorblyfsels in Suid-Afrikaanse blanke en swart persone. Data kom van Suid-Afrikaanse blankes en swartes vanaf die Raymond Dart Skeletale Versameling wat in die Department Anatomiese Wetenskappe, Universiteit van die Witwatesrrand gehuisves word.

Slegs skeletale oorskot waarvan die ras en geslag bekend was, is ingesluit. Die ouderdomspektrum van die studiemateriaal was tussen die ouderdom van 20 en 89 jaar. Die maksimumlengte van die femur (FL), nekskaghoek (NSA), neklengte (NL), maksimum vertikale deursnee van die femurkop (VDH), intertroganteriese as van die apeks (ITAAL), proksimale breedte van die femur (VHA), en laterale kondielhoogte (LCH) is in elke geval gemeet. Hierdie parameters van die femur word gedefinieer en gemeet deur van duidelike anatomiese bakens en standaardtegnieke gebruik te maak. Vir maksimum femurlengte is die gemiddeld van 'n paar in die statistieke gebruik weens die groter betroubaarheid van 'n gemiddeld. Wanneer die been van slegs een kant beskikbaar is, is 'n aanpassing in 'n vergelyking wat op die gemiddeld gebaseer is onnodig aangesien daar geen beduidende verskil tussen die beenlengtes van die twee kante bestaan nie. Om intra-observeerdervariasie te minimaliseer is alle mates tweemaal geneem en die gemiddeld aangeteken. Die data is geanaliseer deur van verskeie prosedures van 'n PC

weergawe van die SAS sagtewareprogram gebruik te maak. Die statistiese analise het uit beskrywende statistieke, Studente se t-toets, korrelasie-analise en regressie-analise bestaan.

Elke veranderlike is ingevolge die gemiddelde, standaardafwyking, mediaan, en rykwydte vir elke ras en geslag sowel as die totale studiemateriaal beskryf. Die gemiddelde femurlengte van die blanke mans in die huidige studie is aansienlik langer as dié van die Amerikaanse mans van die Terry Anatomiese Versameling, die Koreaanse oorlogsafgestorwenes, en moderne forensiese wetenskaplike gevalle wat deur Jantz en Moore-Jansen (1988) voorgehou is. Die gemiddelde lengte in die blanke vroue van die huidige studie verskil nie van dié van die Terry Versameling blanke vroue en die moderne forensiese wetenskaplike gevalle van Jantz en Moore-Jansen (1988) nie. Die gemiddelde femorale lengte van Suid-Afrikaanse swartes van beide geslagte is aansienlike korter as dié van die Amerikaanse swartes.

Wanneer die twee geslagte binne 'n ras vergelyk word, is die mans se femora aansienlik langer. Eweneens is die gemiddelde mates vir alle segmente van die onderskeie rasse hoër in mans as in vroue. Die enigste uitsondering is die nekskaghoek in die swart Suid-Afrikaners, waar daar nie 'n beduidende veskil tussen die twee geslagte is nie. Suid-Afrikaanse blankes en swartes van dieselfde geslag is ook vergelyk. In alle gevalle oortref die mates van die blanke mans dié van swart mans. Daar is nie 'n beduidende verskil tussen die femurlengte en nekskaghoek van blanke en swart vroue nie. Afgesien hiervan oortref die blanke vroue die swart vroue in die oorblywende vyf mates. Dit demonstreer dat bevolkingstandaarde tussen verskeie bevolkingssgroepe verskil, en dat daar 'n behoefte aan bevolkingspesifieke formules, tabelle en vermenigvuldigingsfaktore bestaan.

Die huidige studiemateriaal is met oorstemmende veranderlikes van Simmons et al. (1990) vir Amerikaanse skeletale oorskot en Tamil Nadu skeletale oorskot van Suidelike Indië volgens Prasad et al. (1996) vergelyk.

Die korrelasie-analise tussen femurlengte en die ses segmente het aangedui dat al die segmente aan die proksimale en distale punte van die femur beduidend en positief met femurlengte gekorreleer het. Dit is aanduidend van die hoë voorspellingsvermoë van hierdie segmente in die skatting van femurlengte.

Die interkorrelasiematrikse vir elke ras en geslag het getoon dat al ses die segmente in alle groepe beduidend tussen mekaar gekorreleer het. Die enigste uitsondering is in die swart vroue waar nekskaghoek nie beduidend met neklengte, intertroganteriese as van die apeks, en vertikale deursnee van die femurkop gekorreleer het nie.

Femurlengte is op elke segmentmeting en op 'n kombinasie van segmente vir elke ras en geslag geregresseer. Gevolglik is die bespassende eenvoudige lineêre regressiemodelle van die vorm $y = a + bx$ wat op die kleinste kwadratemetode gebaseer is, vir elke ras en geslag ontwikkel. Daarbenewens is veelvuldige lineêre regressiemodelle van die vorm $y = a = b_1x_1 + b_2x_2$ vir elke ras en geslag ontwikkel ten einde die akkuraatheid van die voorspelling van femurlengte te versterk. Die stapsgewyse seleksieprosedure van SAS is gebruik om die beste kombinasie van segmente te selekteer ten einde femurlengte met 'n hoër graad van akkuraatheid te kan skat. Dertig eenvoudige lineêre regressies en vier veelvoudige lineêre regressievergelykings word getoon. Die vergelykings met hoër koëffisiënte vir die vasstelling van laer standaard skattingsfoute is die keusevergelykings.

Sodra die lengte van die femur bepaal is, kan dit gebruik word om die lengte van die individu deur middel van die beskikbare regressievergelykings te bepaal.

Sodanige skatting van femorale lengte en lengte van die individu volgens die afmetings van die proksimale en distale punte van die femur het potensiaal vir aanwending in fisiese antropologie, mediese reg, en forensiese indentifisering van 'n individu.

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APPENDIX-A: THE R-SQUARE SELECTION METHOD

```
grp=wm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

R-Square Selection Method

Number in
  Model      R-Square    Variables in Model

       1       0.7353    nl
       1       0.7139    nsa
       1       0.6505    lch
       1       0.6398    vha
       1       0.5857    itaal
       1       0.3578    vdh
-----------------------------------------------
       2       0.8270    nsa nl
       2       0.8055    nsa lch
       2       0.7969    nl lch
       2       0.7830    nsa itaal
       2       0.7806    nsa vha
       2       0.7614    nl vdh
       2       0.7613    nl vha
       2       0.7382    nsa vdh
       2       0.7380    nl itaal
       2       0.7184    vha lch
       2       0.7061    itaal lch
       2       0.6642    itaal vha
       2       0.6538    vdh lch
       2       0.6427    vdh vha
       2       0.5995    itaal vdh
-----------------------------------------------
       3       0.8535    nsa nl lch
       3       0.8339    nsa nl vdh
       3       0.8315    nsa nl vha
       3       0.8277    nsa nl itaal
       3       0.8193    nsa itaal lch
       3       0.8158    nsa vha lch
       3       0.8055    nsa vdh lch
       3       0.7994    nl vha lch
       3       0.7985    nl vdh lch
       3       0.7981    nl itaal lch
       3       0.7930    nsa itaal vha
       3       0.7842    nsa itaal vdh
       3       0.7813    nsa vdh vha
       3       0.7692    nl vdh vha
       3       0.7624    nl itaal vha
       3       0.7622    nl itaal vdh
       3       0.7265    itaal vha lch
```

```
grp=wm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

R-Square Selection Method

Number in
  Model      R-Square    Variables in Model

       3       0.7063    itaal vdh lch
       3       0.6648    itaal vdh vha
-------------------------------------------------
       4       0.8543    nsa nl itaal lch
       4       0.8536    nsa nl vdh lch
       4       0.8535    nsa nl vha lch
       4       0.8349    nsa nl vdh vha
       4       0.8341    nsa nl itaal vdh
       4       0.8316    nsa nl itaal vha
       4       0.8209    nsa itaal vha lch
       4       0.8203    nsa itaal vdh lch
       4       0.8168    nsa vdh vha lch
       4       0.8029    nl itaal vha lch
       4       0.8012    nl itaal vdh lch
       4       0.7999    nl vdh vha lch
       4       0.7931    nsa itaal vdh vha
       4       0.7729    nl itaal vdh vha
       4       0.7286    itaal vdh vha lch
-------------------------------------------------
       5       0.8547    nsa nl itaal vdh lch
       5       0.8545    nsa nl itaal vha lch
       5       0.8536    nsa nl vdh vha lch
       5       0.8356    nsa nl itaal vdh vha
       5       0.8226    nsa itaal vdh vha lch
       5       0.8043    nl itaal vdh vha lch
-------------------------------------------------
       6       0.8548    nsa nl itaal vdh vha lch
```

```
grp=bm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

R-Square Selection Method

Number in
  Model      R-Square    Variables in Model

      1        0.6443    vha
      1        0.6399    nl
      1        0.6239    itaal
      1        0.5890    lch
      1        0.4596    vdh
      1        0.3172    nsa
------------------------------------------------
      2        0.7248    nl lch
      2        0.7143    nl vha
      2        0.7093    nl vdh
      2        0.7014    itaal lch
      2        0.6968    vha lch
      2        0.6882    nl itaal
      2        0.6875    nsa vha
      2        0.6850    itaal vha
      2        0.6668    nsa nl
      2        0.6652    vdh vha
      2        0.6572    nsa itaal
      2        0.6512    itaal vdh
      2        0.6456    vdh lch
      2        0.6338    nsa lch
      2        0.5937    nsa vdh
------------------------------------------------
      3        0.7492    nl vdh lch
      3        0.7458    nl vha lch
      3        0.7390    nl itaal lch
      3        0.7362    nsa nl lch
      3        0.7347    nsa nl vdh
      3        0.7343    nl vdh vha
      3        0.7332    nsa nl vha
      3        0.7224    nsa vha lch
      3        0.7215    itaal vha lch
      3        0.7208    nl itaal vha
      3        0.7192    nl itaal vdh
      3        0.7181    nsa itaal lch
      3        0.7119    nsa itaal vha
      3        0.7106    nsa vdh vha
      3        0.7104    itaal vdh lch
      3        0.7069    vdh vha lch
      3        0.7056    nsa nl itaal
```

```
grp=bm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

R-Square Selection Method

Number in
  Model      R-Square    Variables in Model

       3       0.6905    nsa vdh lch
       3       0.6897    nsa itaal vdh
--------------------------------------------------
       4       0.7635    nsa nl vdh lch
       4       0.7574    nsa nl vha lch
       4       0.7574    nl vdh vha lch
       4       0.7549    nsa nl vdh vha
       4       0.7528    nl itaal vdh lch
       4       0.7493    nl itaal vha lch
       4       0.7485    nsa nl itaal lch
       4       0.7402    nsa nl itaal vdh
       4       0.7385    nsa itaal vha lch
       4       0.7374    nsa nl itaal vha
       4       0.7359    nl itaal vdh vha
       4       0.7355    nsa vdh vha lch
       4       0.7311    nsa itaal vdh lch
       4       0.7257    itaal vdh vha lch
       4       0.7244    nsa itaal vdh vha
--------------------------------------------------
       5       0.7710    nsa nl vdh vha lch
       5       0.7654    nsa nl itaal vdh lch
       5       0.7598    nsa nl itaal vha lch
       5       0.7582    nl itaal vdh vha lch
       5       0.7553    nsa nl itaal vdh vha
       5       0.7456    nsa itaal vdh vha lch
--------------------------------------------------
       6       0.7712    nsa nl itaal vdh vha lch
```

```
grp=wf

The REG Procedure
Model: MODEL1
Dependent Variable: fl

R-Square Selection Method

Number in
  Model      R-Square    Variables in Model

       1       0.7981    nsa
       1       0.7024    vha
       1       0.6884    nl
       1       0.6506    lch
       1       0.6322    itaal
       1       0.4200    vdh
---------------------------------------------------
       2       0.8302    nsa vha
       2       0.8146    nsa itaal
       2       0.8144    nsa lch
       2       0.8101    nsa nl
       2       0.8099    nsa vdh
       2       0.7552    nl vha
       2       0.7448    nl lch
       2       0.7287    vha lch
       2       0.7199    nl itaal
       2       0.7114    itaal vha
       2       0.7098    nl vdh
       2       0.7044    vdh vha
       2       0.6892    itaal lch
       2       0.6516    vdh lch
       2       0.6323    itaal vdh
---------------------------------------------------
       3       0.8313    nsa nl vha
       3       0.8310    nsa vha lch
       3       0.8303    nsa vdh vha
       3       0.8302    nsa itaal vha
       3       0.8198    nsa nl lch
       3       0.8187    nsa itaal lch
       3       0.8174    nsa nl itaal
       3       0.8170    nsa nl vdh
       3       0.8161    nsa vdh lch
       3       0.8157    nsa itaal vdh
       3       0.7662    nl vha lch
       3       0.7557    nl vdh vha
       3       0.7554    nl itaal vha
       3       0.7471    nl itaal lch
       3       0.7450    nl vdh lch
       3       0.7373    vdh vha lch
       3       0.7299    itaal vha lch
```

```
rp=wf

he REG Procedure
odel: MODEL1
ependent Variable: fl

-Square Selection Method

umber in
 Model      R-Square    Variables in Model

     3        0.7177    itaal vdh vha
     3        0.6926    itaal vdh lch
-----------------------------------------------
     4        0.8320    nsa nl vha lch
     4        0.8315    nsa vdh vha lch
     4        0.8313    nsa nl vdh vha
     4        0.8313    nsa nl itaal vha
     4        0.8311    nsa itaal vha lch
     4        0.8304    nsa itaal vdh vha
     4        0.8213    nsa nl itaal lch
     4        0.8210    nsa nl vdh lch
     4        0.8189    nsa nl itaal vdh
     4        0.8188    nsa itaal vdh lch
     4        0.7696    nl vdh vha lch
     4        0.7667    nl itaal vha lch
     4        0.7562    nl itaal vdh vha
     4        0.7472    nl itaal vdh lch
     4        0.7409    itaal vdh vha lch
-----------------------------------------------
     5        0.8323    nsa nl vdh vha lch
     5        0.8322    nsa nl itaal vha lch
     5        0.8315    nsa itaal vdh vha lch
     5        0.8313    nsa nl itaal vdh vha
     5        0.8217    nsa nl itaal vdh lch
     5        0.7696    nl itaal vdh vha lch
-----------------------------------------------
     6        0.8324    nsa nl itaal vdh vha lch
```

```
grp=bf

The REG Procedure
Model: MODEL1
Dependent Variable: fl

R-Square Selection Method

Number in
  Model      R-Square    Variables in Model

       1       0.5733    itaal
       1       0.4926    lch
       1       0.4618    vha
       1       0.4064    nl
       1       0.4018    vdh
       1       0.0689    nsa
--------------------------------------------------
       2       0.6292    itaal lch
       2       0.6026    nl lch
       2       0.5894    vha lch
       2       0.5872    nsa itaal
       2       0.5865    itaal vdh
       2       0.5864    itaal vha
       2       0.5803    nl itaal
       2       0.5616    nl vdh
       2       0.5254    nl vha
       2       0.5236    vdh lch
       2       0.5086    vdh vha
       2       0.4993    nsa lch
       2       0.4731    nsa vha
       2       0.4329    nsa vdh
       2       0.4275    nsa nl
--------------------------------------------------
       3       0.6410    nl itaal lch
       3       0.6368    itaal vha lch
       3       0.6351    nsa itaal lch
       3       0.6295    nl vha lch
       3       0.6293    itaal vdh lch
       3       0.6210    nl vdh lch
       3       0.6061    nsa nl lch
       3       0.6017    nl itaal vdh
       3       0.6006    nsa itaal vdh
       3       0.5972    nsa itaal vha
       3       0.5938    itaal vdh vha
       3       0.5931    nsa nl itaal
       3       0.5922    nsa vha lch
       3       0.5918    nl itaal vha
       3       0.5905    vdh vha lch
       3       0.5782    nl vdh vha
       3       0.5762    nsa nl vdh
```

```
grp=bf

The REG Procedure
Model: MODEL1
Dependent Variable: fl

R-Square Selection Method

Number in
  Model      R-Square    Variables in Model

      3        0.5328    nsa vdh lch
      3        0.5218    nsa vdh vha
---------------------------------------------------
      4        0.6467    nl itaal vha lch
      4        0.6456    nsa nl itaal lch
      4        0.6428    nl itaal vdh lch
      4        0.6413    nsa itaal vha lch
      4        0.6369    itaal vdh vha lch
      4        0.6354    nsa itaal vdh lch
      4        0.6337    nl vdh vha lch
      4        0.6318    nsa nl vha lch
      4        0.6261    nsa nl vdh lch
      4        0.6141    nsa nl itaal vdh
      4        0.6056    nl itaal vdh vha
      4        0.6054    nsa itaal vdh vha
      4        0.6018    nsa nl itaal vha
      4        0.5938    nsa vdh vha lch
      4        0.5889    nsa nl vdh vha
---------------------------------------------------
      5        0.6503    nsa nl itaal vha lch
      5        0.6480    nsa nl itaal vdh lch
      5        0.6471    nl itaal vdh vha lch
      5        0.6413    nsa itaal vdh vha lch
      5        0.6370    nsa nl vdh vha lch
      5        0.6164    nsa nl itaal vdh vha
---------------------------------------------------
      6        0.6511    nsa nl itaal vdh vha lch
```

APPENDIX-B: THE ADJUSTED R-SQUARE SELECTION METHOD

```
grp=wm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

Adjusted R-Square Selection Method

Number in     Adjusted
  Model       R-Square     R-Square     Variables in Model

      3        0.8490       0.8535      nsa nl lch
      4        0.8482       0.8543      nsa nl itaal lch
      4        0.8474       0.8536      nsa nl vdh lch
      4        0.8474       0.8535      nsa nl vha lch
      5        0.8470       0.8547      nsa nl itaal vdh lch
      5        0.8468       0.8545      nsa nl itaal vha lch
      5        0.8458       0.8536      nsa nl vdh vha lch
      6        0.8454       0.8548      nsa nl itaal vdh vha lch
      3        0.8288       0.8339      nsa nl vdh
      4        0.8279       0.8349      nsa nl vdh vha
      4        0.8272       0.8341      nsa nl itaal vdh
      5        0.8268       0.8356      nsa nl itaal vdh vha
      3        0.8263       0.8315      nsa nl vha
      4        0.8245       0.8316      nsa nl itaal vha
      2        0.8234       0.8270      nsa nl
      3        0.8223       0.8277      nsa nl itaal
      3        0.8137       0.8193      nsa itaal lch
      4        0.8134       0.8209      nsa itaal vha lch
      5        0.8131       0.8226      nsa itaal vdh vha lch
      4        0.8128       0.8203      nsa itaal vdh lch
      3        0.8101       0.8158      nsa vha lch
      4        0.8091       0.8168      nsa vdh vha lch
      2        0.8015       0.8055      nsa lch
      3        0.7994       0.8055      nsa vdh lch
      4        0.7945       0.8029      nl itaal vha lch
      5        0.7939       0.8043      nl itaal vdh vha lch
      3        0.7931       0.7994      nl vha lch
      4        0.7929       0.8012      nl itaal vdh lch
      2        0.7928       0.7969      nl lch
      3        0.7922       0.7985      nl vdh lch
      3        0.7918       0.7981      nl itaal lch
      4        0.7914       0.7999      nl vdh vha lch
      3        0.7866       0.7930      nsa itaal vha
      4        0.7844       0.7931      nsa itaal vdh vha
      2        0.7785       0.7830      nsa itaal
      3        0.7775       0.7842      nsa itaal vdh
      2        0.7761       0.7806      nsa vha
      3        0.7745       0.7813      nsa vdh vha
      4        0.7633       0.7729      nl itaal vdh vha
      3        0.7620       0.7692      nl vdh vha
```

```
grp=wm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

Adjusted R-Square Selection Method

Number in    Adjusted
  Model      R-Square     R-Square     Variables in Model

       2       0.7563       0.7613     nl vha
       3       0.7549       0.7624     nl itaal vha
       3       0.7547       0.7622     nl itaal vdh
       2       0.7328       0.7382     nsa vdh
       2       0.7326       0.7380     nl itaal
       1       0.7326       0.7353     nl
       3       0.7180       0.7265     itaal vha lch
       4       0.7172       0.7286     itaal vdh vha lch
       2       0.7126       0.7184     vha lch
       1       0.7109       0.7139     nsa
       3       0.7109       0.7196     vdh vha lch
       2       0.7000       0.7061     itaal lch
       3       0.6972       0.7063     itaal vdh lch
       2       0.6572       0.6642     itaal vha
       3       0.6543       0.6648     itaal vdh vha
       1       0.6470       0.6505     lch
       2       0.6467       0.6538     vdh lch
       1       0.6361       0.6398     vha
       2       0.6353       0.6427     vdh vha
       2       0.5913       0.5995     itaal vdh
       1       0.5815       0.5857     itaal
       1       0.3512       0.3578     vdh
```

```
grp=bm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

Adjusted R-Square Selection Method

Number in     Adjusted
  Model       R-Square     R-Square     Variables in Model

       5        0.7588       0.7710     nsa nl vdh vha lch
       6        0.7565       0.7712     nsa nl itaal vdh vha lch
       4        0.7535       0.7635     nsa nl vdh lch
       5        0.7530       0.7654     nsa nl itaal vdh lch
       4        0.7472       0.7574     nsa nl vha lch
       4        0.7472       0.7574     nl vdh vha lch
       5        0.7470       0.7598     nsa nl itaal vha lch
       5        0.7454       0.7582     nl itaal vdh vha lch
       4        0.7446       0.7549     nsa nl vdh vha
       4        0.7424       0.7528     nl itaal vdh lch
       5        0.7423       0.7553     nsa nl itaal vdh vha
       3        0.7414       0.7492     nl vdh lch
       4        0.7388       0.7493     nl itaal vha lch
       4        0.7379       0.7485     nsa nl itaal lch
       3        0.7379       0.7458     nl vha lch
       5        0.7321       0.7456     nsa itaal vdh vha lch
       3        0.7309       0.7390     nl itaal lch
       4        0.7293       0.7402     nsa nl itaal vdh
       3        0.7280       0.7362     nsa nl lch
       4        0.7275       0.7385     nsa itaal vha lch
       3        0.7265       0.7347     nsa nl vdh
       4        0.7264       0.7374     nsa nl itaal vha
       3        0.7260       0.7343     nl vdh vha
       3        0.7249       0.7332     nsa nl vha
       4        0.7247       0.7359     nl itaal vdh vha
       4        0.7243       0.7355     nsa vdh vha lch
       4        0.7198       0.7311     nsa itaal vdh lch
       2        0.7191       0.7248     nl lch
       4        0.7141       0.7257     itaal vdh vha lch
       3        0.7137       0.7224     nsa vha lch
       4        0.7128       0.7244     nsa itaal vdh vha
       3        0.7128       0.7215     itaal vha lch
       3        0.7121       0.7208     nl itaal vha
       3        0.7104       0.7192     nl itaal vdh
       3        0.7093       0.7181     nsa itaal lch
       2        0.7084       0.7143     nl vha
       2        0.7033       0.7093     nl vdh
       3        0.7029       0.7119     nsa itaal vha
       3        0.7016       0.7106     nsa vdh vha
       3        0.7013       0.7104     itaal vdh lch
```

```
grp=bm

The REG Procedure
Model: MODEL1
Dependent Variable: fl

Adjusted R-Square Selection Method

Number in    Adjusted
  Model      R-Square     R-Square     Variables in Model

      3        0.6964       0.7056     nsa nl itaal
      2        0.6952       0.7014     itaal lch
      2        0.6906       0.6968     vha lch
      3        0.6842       0.6938     itaal vdh vha
      2        0.6817       0.6882     nl itaal
      2        0.6810       0.6875     nsa vha
      3        0.6809       0.6905     nsa vdh lch
      3        0.6800       0.6897     nsa itaal vdh
      2        0.6785       0.6850     itaal vha
      2        0.6600       0.6668     nsa nl
      2        0.6583       0.6652     vdh vha
      2        0.6502       0.6572     nsa itaal
      2        0.6440       0.6512     itaal vdh
      1        0.6406       0.6443     vha
      2        0.6383       0.6456     vdh lch
      1        0.6363       0.6399     nl
      2        0.6263       0.6338     nsa lch
      1        0.6201       0.6239     itaal
      2        0.5853       0.5937     nsa vdh
      1        0.5848       0.5890     lch
      1        0.4541       0.4596     vdh
      1        0.3103       0.3172     nsa
```

```
rp=wf

he REG Procedure
odel: MODEL1
ependent Variable: fl

Adjusted R-Square Selection Method

Number in     Adjusted
  Model       R-Square      R-Square     Variables in Model

       2       0.8267        0.8302      nsa vha
       3       0.8260        0.8313      nsa nl vha
       3       0.8258        0.8310      nsa vha lch
       3       0.8250        0.8303      nsa vdh vha
       3       0.8249        0.8302      nsa itaal vha
       4       0.8249        0.8320      nsa nl vha lch
       4       0.8244        0.8315      nsa vdh vha lch
       4       0.8242        0.8313      nsa nl vdh vha
       4       0.8242        0.8313      nsa nl itaal vha
       4       0.8240        0.8311      nsa itaal vha lch
       5       0.8234        0.8323      nsa nl vdh vha lch
       5       0.8233        0.8322      nsa nl itaal vha lch
       4       0.8232        0.8304      nsa itaal vdh vha
       5       0.8225        0.8315      nsa itaal vdh vha lch
       5       0.8224        0.8313      nsa nl itaal vdh vha
       6       0.8216        0.8324      nsa nl itaal vdh vha lch
       3       0.8142        0.8198      nsa nl lch
       4       0.8138        0.8213      nsa nl itaal lch
       4       0.8135        0.8210      nsa nl vdh lch
       3       0.8130        0.8187      nsa itaal lch
       5       0.8122        0.8217      nsa nl itaal vdh lch
       3       0.8117        0.8174      nsa nl itaal
       3       0.8113        0.8170      nsa nl vdh
       4       0.8113        0.8189      nsa nl itaal vdh
       4       0.8112        0.8188      nsa itaal vdh lch
       2       0.8108        0.8146      nsa itaal
       2       0.8106        0.8144      nsa lch
       3       0.8104        0.8161      nsa vdh lch
       3       0.8099        0.8157      nsa itaal vdh
       2       0.8062        0.8101      nsa nl
       2       0.8059        0.8099      nsa vdh
       1       0.7960        0.7981      nsa
       4       0.7599        0.7696      nl vdh vha lch
       3       0.7589        0.7662      nl vha lch
       5       0.7574        0.7696      nl itaal vdh vha lch
       4       0.7569        0.7667      nl itaal vha lch
       2       0.7502        0.7552      nl vha
       3       0.7481        0.7557      nl vdh vha
       3       0.7477        0.7554      nl itaal vha
       4       0.7459        0.7562      nl itaal vdh vha
```

```
p=wf

e REG Procedure
del: MODEL1
pendent Variable: fl

justed R-Square Selection Method

mber in    Adjusted
Model      R-Square     R-Square     Variables in Model

    3        0.7392       0.7471     nl itaal lch
    3        0.7370       0.7450     nl vdh lch
    4        0.7366       0.7472     nl itaal vdh lch
    4        0.7300       0.7409     itaal vdh vha lch
    3        0.7291       0.7373     vdh vha lch
    2        0.7231       0.7287     vha lch
    3        0.7215       0.7299     itaal vha lch
    2        0.7141       0.7199     nl itaal
    3        0.7130       0.7217     nl itaal vdh
    3        0.7089       0.7177     itaal vdh vha
    2        0.7054       0.7114     itaal vha
    2        0.7039       0.7098     nl vdh
    1        0.6993       0.7024     vha
    2        0.6983       0.7044     vdh vha
    1        0.6853       0.6884     nl
    3        0.6829       0.6926     itaal vdh lch
    2        0.6828       0.6892     itaal lch
    1        0.6470       0.6506     lch
    2        0.6444       0.6516     vdh lch
    1        0.6285       0.6322     itaal
    2        0.6248       0.6323     itaal vdh
    1        0.4141       0.4200     vdh
```

```
grp=bf

The REG Procedure
Model: MODEL1
Dependent Variable: fl

Adjusted R-Square Selection Method

Number in    Adjusted
  Model      R-Square     R-Square    Variables in Model

      4       0.6318       0.6467     nl itaal vha lch
      5       0.6317       0.6503     nsa nl itaal vha lch
      4       0.6307       0.6456     nsa nl itaal lch
      3       0.6298       0.6410     nl itaal lch
      5       0.6292       0.6480     nsa nl itaal vdh lch
      6       0.6286       0.6511     nsa nl itaal vdh vha lch
      5       0.6284       0.6471     nl itaal vdh vha lch
      4       0.6278       0.6428     nl itaal vdh lch
      4       0.6262       0.6413     nsa itaal vha lch
      3       0.6254       0.6368     itaal vha lch
      3       0.6237       0.6351     nsa itaal lch
      5       0.6222       0.6413     nsa itaal vdh vha lch
      4       0.6216       0.6369     itaal vdh vha lch
      2       0.6216       0.6292     itaal lch
      4       0.6201       0.6354     nsa itaal vdh lch
      4       0.6182       0.6337     nl vdh vha lch
      3       0.6179       0.6295     nl vha lch
      3       0.6177       0.6293     itaal vdh lch
      5       0.6177       0.6370     nsa nl vdh vha lch
      4       0.6163       0.6318     nsa nl vha lch
      4       0.6104       0.6261     nsa nl vdh lch
      3       0.6092       0.6210     nl vdh lch
      4       0.5978       0.6141     nsa nl itaal vdh
      5       0.5960       0.6164     nsa nl itaal vdh vha
      2       0.5944       0.6026     nl lch
      3       0.5938       0.6061     nsa nl lch
      3       0.5893       0.6017     nl itaal vdh
      4       0.5890       0.6056     nl itaal vdh vha
      4       0.5888       0.6054     nsa itaal vdh vha
      3       0.5881       0.6006     nsa itaal vdh
      4       0.5851       0.6018     nsa nl itaal vha
      3       0.5846       0.5972     nsa itaal vha
      3       0.5811       0.5938     itaal vdh vha
      2       0.5810       0.5894     vha lch
      3       0.5804       0.5931     nsa nl itaal
      3       0.5794       0.5922     nsa vha lch
      3       0.5791       0.5918     nl itaal vha
      2       0.5787       0.5872     nsa itaal
      2       0.5780       0.5865     itaal vdh
      2       0.5779       0.5864     itaal vha
```

```
grp=bf

The REG Procedure
Model: MODEL1
Dependent Variable: fl

Adjusted R-Square Selection Method

Number in    Adjusted
  Model      R-Square     R-Square    Variables in Model

       4       0.5767       0.5938    nsa vdh vha lch
       2       0.5717       0.5803    nl itaal
       4       0.5716       0.5889    nsa nl vdh vha
       1       0.5689       0.5733    itaal
       3       0.5650       0.5782    nl vdh vha
       3       0.5630       0.5762    nsa nl vdh
       2       0.5526       0.5616    nl vdh
       3       0.5198       0.5344    nsa nl vha
       3       0.5182       0.5328    nsa vdh lch
       2       0.5156       0.5254    nl vha
       2       0.5137       0.5236    vdh lch
       3       0.5069       0.5218    nsa vdh vha
       2       0.4985       0.5086    vdh vha
       2       0.4890       0.4993    nsa lch
       1       0.4874       0.4926    lch
       2       0.4622       0.4731    nsa vha
       1       0.4564       0.4618    vha
       2       0.4213       0.4329    nsa vdh
       2       0.4157       0.4275    nsa nl
       1       0.4004       0.4064    nl
       1       0.3957       0.4018    vdh
       1       0.0594       0.0689    nsa
```