Soft Tissue Evaluation as a Correction Factor for Stature Estimation

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DECLARATION

I, Mubarak Ariyo Bidmos, declare that this thesis is my own work. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

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…………day of……………………….., 2009.

Dedicated to

My family,
Mujidah, Abdur-Rahman, Hamdallah and Imraan,
for all their support and encouragement.

ABSTRACT

The anatomical method of stature estimation, as it is applied today, was introduced by Georges Fully in 1956. While some authors consider it to be the most accurate method of stature estimation, others regard it to be inadequate as it underestimates living stature, possibly due to an error in the magnitude of Fully's soft tissue indices. Nevertheless, Fully's technique (1956) remains the only usable method for formulation of regression equations for estimation of stature in South Africa. Since long bones of the upper and lower limbs are sometimes recovered in various states of fragmentation, this study investigates the usefulness of measurements of fragments of the femur and intact metatarsals from cadaver derived skeletons of indigenous South Africans (ISA) and South Africans of European Descent (SAED) in stature reconstruction. In addition, the reliability of Fully's soft tissue correction index was assessed on a sample of living ISA males. Analyses of data collected from 240 complete skeletons obtained from the Raymond A. Dart Collection of Human Skeletons revealed that moderate to high correlations exist between measurements of fragments of femur and skeletal height. Subsequently, population and sex specific regression equations for the estimation of skeletal height and maximum length of the femur were derived. The equations derived for the direct estimation of stature from fragments of the femur provide more accurate results compared to the indirect method. Regression equations were also derived from 6 measurements of metatarsals. The standard error of estimate for equations derived from metatarsal lengths was lower than that obtained for other skeletal elements studied so far for stature estimation in South Africans with the exception of intact long bones and fragments of the femur. Fully (1956) instructed that a soft tissue correction factor should be added to skeletal height in order to obtain an estimate of living stature. The estimate of

living stature obtained from the addition of appropriate soft tissue indices of Fully (1956) and Raxter *et al*. (2006) to skeletal height calculated from MRI scan of 28 living subjects was found to be significantly lower than the measured living stature. This necessitated the derivation of new soft tissue index for ISA males. The accuracy of this new soft tissue correction index was found to be 100%.

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Introduction

1.1 Forensic anthropology: A brief introduction

In 1894 Dwight proposed that as human populations differ in physical characteristics, it is expected that their bones should exhibit a variety of discernable differences. It should therefore be possible to obtain demographic information such as sex, population affinity, stature and age at the time of death by taking standardized measurements on these bones (Thomas, 1995). The ideas and findings of Dwight formed the basis for the foundation and development of a new field in forensic science termed forensic anthropology (Thomas, 1995). Forensic anthropology is a branch of forensic medicine that is concerned with the building of antemortem histories of individuals from skeletonised remains (Krogman and İşcan, 1986). It is therefore useful in a medicolegal context in suspected cases of infanticide, homicide and suicide.

As it is often difficult or impossible to identify individuals from soft tissue remains, such as in cases of large scale disasters, bones can serve as important tools for human identification as they are resistant not only to the effect of heat but to other environmental factors leading to degradation. As a result, osteometric standards have been developed for forensic purposes from measurements of the skull and most components of the postcranial skeleton. Most of these formulae have been shown to be population specific and their application to populations other than those from which they have been derived is strongly discouraged (Trotter and Gleser, 1958; Lundy, 1983a; Holland, 1995). In 1997, Steyn and co-workers noted that most of the standards used for human identification in South Africa were derived from international sources due to the lack of local standards, and this led to difficulty in accurately identifying individuals from skeletal remains (Steyn *et al.*, 1997).

In response to these observations, studies were conducted for the purpose of establishing local standards for human identification in South Africa from the skull (Steyn and İşcan, 1998; Franklin *et al.*, 2005; Ryan and Bidmos, 2007) and postcranial skeleton (e.g. Steyn and İşcan, 1997, 1999; Asala, 2001, 2002; Patriquin *et al*., 2002, 2005; Dayal, 2002; Bidmos and Asala, 2003, 2004, 2005; Bidmos and Dayal, 2003, 2004). While it is strongly advised that collection of data from as many components of the human skeleton for forensic purposes in South Africa should be a continuous exercise, it is equally important that the results of these studies are verified at opportune intervals. Very few studies have been conducted so far for validation purposes (Bidmos, 2005a; Oettlé *et al*., 2005; Pretorius *et al*., 2006; Robinson and Bidmos, 2009).

1.2 Analysis of skeletal remains

In analyzing skeletal remains that are recovered either in complete or fragmentary states, a practitioner of forensic anthropology should be able to: (1) estimate the age; (2) determine the population affinity; (3) determine the sex; and (4) estimate the stature of an individual/s from these remains. Brief accounts of some of the studies that have been conducted for the purpose of establishing the aforementioned demographic information are as follows:

1.2.1 Estimation of age

Age in the adult is the most difficult piece of demographic information to estimate because of the irregularity and inconsistency of bone remodeling that is associated with age changes (İşcan and Loth, 1997).While this is one of the most essential pieces of information necessary for identification of an individual, precise estimation of age in adults from the human skeleton still creates a huge challenge to forensic and physical anthropologists. The most reliable way to estimate age in children is based on tooth eruption and ossification of carpal bones as each follows a definite and consistent pattern (Loth and İşcan, 2000).

Morphological assessment of the closure of cranial sutures was the most common method used to estimate age in adults. As cranial sutures close with increasing age, older individuals tend to have closed sutures while skulls of younger individuals present with opened sutures. This method is quite complex and has been shown to be inaccurate (Krogman and İşcan, 1986; Rosing *et al.,* 2007), thereby necessitating the use of other methods such as observations of the medial surfaces of the pubic symphysis (Krogman and İşcan, 1986) and the sternal end of ribs 3,4 and 5 (Loth and İşcan, 2000). Loth and İşcan (2000) observed that the most consistently reliable technique for determining age from the adult skeleton is by examination of the sternal end of the ribs; however Rösing *et al.* (2007) disagreed with this observation and advised caution when using metamorphosis of rib ends in the estimation of age as this feature is highly dependent on individual activity patterns.

Rösing and co-workers (2007) classified the different methods of age estimation into four groups based on their degree of accuracy. The use of cranial sutures alone, occlusal tooth wear, and metamorphosis of rib ends have the least accuracy due to “high stochastic error” (Rösing *et al.*, 2007). Methods that combine different morphological traits such as skull sutures, bone loss and changes in the pubic symphysis, to mention a few, do yield a higher accuracy compared to those features described above but the standard error may still be as high as 10 years. A more accurate estimate of age can be obtained from methods that utilize histological, radiological and macroscopic features of teeth and histological features of bones (Rösing *et al.*, 2007). The racemization of aspartic acid according to Rösing and co-workers (2007) provides the most accurate method for the estimation of physiological or skeletal age in adults.

Recent trend in forensic age diagnosis focuses on the use of radiographic imaging technique (e.g. X-rays, CT scans) as a tool for the estimation of skeletal age and also for the assessment of biological growth. Due to an increase in cross border migration especially from developing to developed countries, numerous studies have been devoted to the estimation of skeletal age of living subjects in order to ascertain whether these individuals are criminally liable or not (Schmeling *et al.*, 2006a). As part of the recommendation made by the Study Group on Forensic Age Diagnostics, forensic age estimation should amongst other methods include a physical and dental examination, X-ray of the left hand, and radiological assessment of the medial end of the clavicle (Schmeling *et al.*, 2006b). Currently, the developmental status of carpal bones is one of the most important criteria for forensic diagnosis of age (Cameriere *et al.*, 2006a; Schmeling *et al.*, 2006a).

1.2.2 Determination of population affinity (race)

According to Krogman and İşcan (1986), human beings traditionally are assigned to three major population groups –"Caucasoid", "Mongoloid" and "Negroid". Determination of population affinity, just like estimation of age in the adult skeleton, also poses a major challenge to even the best of practitioners of forensic anthropology due to the admixture and overlap of population groups (İşcan and Loth, 1997). The use of cranio-facial morphology by visual observation is currently the best indicator for assigning population affinity (İşcan and Loth, 1997). The use of this method has a disadvantage of being complex and often requires many years of experience on the part of the forensic anthropologist (İşcan, 2000). Due to these limitations of the non-metrical or morphological method, attempts were also made with the metrical method in the assessment and determination of population group from skeletal remains.

Measurements of the skull (Giles and Elliot, 1962; Birkby, 1966; İşcan and Steyn, 1999) and pelvis (DiBennardo and Taylor, 1983; Patriquin *et al.*, 2002) have been used in the determination of population affinity with various degrees of success. Since these bones may be recovered in different states of fragmentation or are sometimes not present at all for analysis in forensic cases, selected tarsal elements were subjected to discriminant function and canonical variant analyses (Pickering, 1986; Kidd and Oxnard, 2002; Bidmos, 2006a). The average accuracies in correct assignment of population affinity obtained from these compare well with those presented for the skull and the pelvis.

1.2.3 Determination of Sex

Sex determination from skeletal remains is crucial in skeletal analysis as it decreases the possible matches by approximately fifty percent. Two methods have been suggested and are widely used for this purpose. The morphological, or non-metrical, method involves the visual observation of sexual traits on bones that exhibit sexual dimorphism. Examples of such traits include the wide subpubic angle in female pelves and the presence of an occipital hook in male skulls. The recognition of these traits by an experienced observer can yield accurate results in correct sex classification. The pelvis is arguably the most reliable bone for sex determination as it allows for parturition in females (Lundy, 1998). Although the pelvis (Krogman and İşcan, 1986) and mandible (Loth and Henneberg, 1996) yield accuracies close to 99% when using this method, these bones are not always present in forensic cases.

As the morphological method is a subjective method requiring expertise in the field (Thieme, 1957; Taylor and DiBennardo, 1982; Introna *et al.*, 1997), attempts have been made at determining sex from other bones (e.g. long bones) that do not display obvious sexual differences. The metrical method involves subjecting a suite of measurements taken on these bones to various forms of metrical analyses of which discriminant function analyses is the most widely used. The use of the metrical method in the determination of sex does not require expertise and it can be repeated to validate the obtained results; however, the equations derived from it are population specific (Steele, 1976; Introna *et al.*, 1998; King *et al.*, 1998).

Metrical analysis of dimensions taken on the skull and mandible (Kajanoja, 1966; Steyn and İşcan, 1998; Franklin *et al.*, 2005; Dayal *et al.*, 2008a), the humerus (Steyn and İşcan, 1999), radius and ulna (Celbis and Agritmis, 2006; Barrier and L'Abbé, 2008), metacarpals (Stojanowski, 1999, Zanella and Brown, 2003, Case and Ross, 2007), the pelvis (Schulter-Ellis *et al*., 1983, 1985; Patriquin *et al*., 2005), the patella (Introna *et al.*, 1998; Bidmos *et al*., 2005; Dayal and Bidmos, 2005), the femur and tibia (Taylor and DiBennardo, 1982; Steyn and İşcan, 1997; King *et al.*, 1998; Asala *et al.*, 2004), tarsal elements (Steele, 1976; Introna *et al*., 1997; Bidmos and Asala, 2003, 2004; Bidmos and Dayal, 2003, 2004; Gualdi-Russo, 2007) and metatarsals (Robling and Ubelaker, 1997) have been used to obtain discriminant function equations with acceptably high average accuracies in correct sex classification.

1.2.4 Estimation of stature

Stature is an important factor that complements other data such as age, population affinity and sex in the identification of an individual from skeletal remains. Three different methods have been suggested and used for the estimation of stature. These are: (a) the anatomical method; (b) the mathematical method; and (c) the femur/stature ratio (Sjøvold, 2000).

The anatomical method involves measurement of all the individual elements of the human skeleton that contribute to living stature. This technique was first suggested by Dwight in 1894 (Lundy, 1983a, b) and was later improved upon by Fully (1956). In order to account for soft tissue elements that form part of the living stature, Fully (1956) also devised correction indices. The anatomical method has the disadvantages of being time consuming and requiring the presence of a complete skeleton, thereby making the mathematical method the most widely used of all methods of stature estimation.

The mathematical method involves the derivation of regression equations, which show linear relationships between the different dimensions of bones and stature. Long bones such as the humerus, radius, ulna, femur, tibia and fibula have been extensively used for this purpose (e.g. Trotter and Gleser, 1952a, 1952b, 1958; Lundy, 1983a, b; Lundy and Feldesman, 1987; De Medonca, 2000; Dayal, 2002). As long bones are often recovered in various states of fragmentation in forensic and archaeological practice, the development and use of other methods became necessary.

Measurements from the skull (Chiba and Terazawa, 1998; Patil and Mody, 2005; Ryan and Bidmos, 2007), fragmentary femora, tibiae and humeri (Steele and McKern, 1969; Steele, 1970; Simmons *et al.*, 1990; De Medonca, 2000; Chibba and

Bidmos, 2007), segments of the femur, radius, ulna and tibia (Mysorekar *et al.*, 1980, 1984) have all been used to derive regression equations for stature estimation. Also, the length of metatarsals (Byers *et al*, 1989), metacarpals (Meadows and Jantz, 1992), hand and feet (Krishan and Sharma, 2007), as well as footprints and shoe prints (Giles and Vallandigham, 1991; Jasuja *et al.*, 1997) have been used in stature reconstruction with various degrees of success. Small compact bones (e.g. talus and calcaneus) have a greater chance of being recovered intact in forensic and archaeological cases compared to long bones and as such they have been used in the estimation of stature of Americans of European and African descent (Holland, 1995) and South Africans (Bidmos and Asala, 2005; Bidmos, 2006b).

1.3 Overview on studies on stature reconstruction: Materials, methodologies and limitations

All studies on stature reconstruction require that the researcher obtain two sets of data from the selected sample. These are (i) the independent or predictor variable (e.g. long bone length, measurements of fragments of long bone) and (ii) dependent or response variable (stature). In an ideal case, direct information should be obtained for both sets of data; however, in most cases this is not feasible as direct information is only obtained for one set of data while the other set of data is estimated (Sjǿvold, 2000). The problem with the latter approach is that "if one kind of data is not known but has to be estimated, the correlations between stature and bone length tend to be underestimated, leading to a slightly higher standard error of stature estimates in comparison to methods based on known stature and known bone lengths" (Sjǿvold, 2000: page 277). Table 1.1 shows the different case scenario and the source of studied material.

Table 1.1 Sources of data for studies on estimation of stature

Cases	Predictor/Independent variable	Response/Dependent variable
1	Bone lengths after death[1]	Living stature[1]
2	Bone lengths after death[1]	Cadaver length[2]
3	Measurements of percutaneous bones or X-ray measurements of extremeties[2]	Living stature[1]
4	Bone lengths after death[1]	Skeletal heigth[2]

[1]Primary data, [2]Secondary data

In case 1, both sets of data were measured directly before (living stature) and after death (long bone lengths). Therefore, the independent and dependent variables are regarded as primary data. Studies by Trotter and Gleser (1952a, 1958) are good examples of this case scenario. In case 2, the independent variable (bone length) is the primary data. The dependent variable i.e. cadaver length, on the other hand, is regarded as the secondary data since it has to be converted to living stature in order to compensate for the increase in length due to rigor mortis (e.g. De Medonça, 2000; Hauser *et al*., 2005; Petrovečki *et al*., 2007).

The primary data in case 3 is the dependent variable (living stature) while measurements of bones obtained from radiographs are regarded as secondary data since they are not measured directly. Also, consideration has to be given to the degree of magnification of the bone length that is regarded as a function of the distance of the X-ray film to the studied bone (Sjøvold, 2000). In essence, bone length is obtained indirectly from measurements on radiographs. The same situation arises when percutaneous landmarks on living subjects are used in the estimation of bone length (e.g. Ozaslan *et al.*, 2003).

In the last case scenario (case 4), the bone length is the primary data. Since stature is estimated from skeletal height (see section 3.3.2., pages 47-60) it is not considered to be primary data (Sjøvold, 2000). Lundy (1983a), Lundy and Feldesman (1997), Dayal (2002), Bidmos and Asala (2005), Bidmos (2006b), Chibba and Bidmos (2007), Dayal *et al*. (2008b) and Raxter *et al*. (2006) are some of the studies that utilized Fully's method in the reconstruction of living stature.

1.4 Stature reconstruction in South Africa and the role of Magnetic Resonance Imaging technique

All studies so far conducted in South Africa have relied on Fully's method (1956) for the estimation of stature. This became necessary as the documented cadaveric lengths as contained in the catalogues of the Raymond A. Dart and Pretoria Collections have been shown to be unreliable (Lundy, 1983a). While some authors (Lundy, 1988; Sciulli *et al*., 1990; Ousley, 1995) regard Fully's technique to be an accurate method of estimation of stature, others (King, 2004; Bidmos, 2005; Raxter et al., 2006) consider it to consistently underestimate living stature. King (2004) and Bidmos (2005b) hypothesized that the inaccuracy of Fully's method might be due to error in Fully's soft tissue correction indices. In addition, Bidmos (2005b) suggested the possibility of population specificity of soft tissue correction indices, but findings of Raxter *et al*. (2006) could not verify this proposal.

As mentioned in section 1.3 above, the ideal situation in stature reconstruction is to obtain primary data for both independent and dependent variables. While it is possible to acquire data for stature (independent variable) from living subjects, acquisition of primary data from dried bones of the subjects is not feasible. Consequently, case scenario 3 as described above in which measurements of bones are radiographically determined from X-ray and computed tomography (CT) scan images becomes a reasonable option. However, the use of magnetic resonance imaging technique (MRI) for this purpose is rare. Pelin *et al*. (2005) conducted the only study to date in which MR imaging was used in stature reconstruction. In this study (Pelin *et al*., 2005) sacral and coccygeal measurements were taken on MRI scans of 42 adult male subjects diagnosed with prostate cancer that were undergoing assessment for tumor staging. Living stature of these subjects was subsequently regressed on sacral height, coccygeal height and anterior height of each of the sacral and coccygeal bones. They (2005) observed that the accuracy of the regression equation derived from a combination of selected measurements is better than those derived for measurements of the head and foot while long bone length still remains the best predictor of stature.

Magnetic resonance imaging (MRI) is a technique that is used primarily for the production of images of internal structures of the human body. Felix Bloch and Edward Purcell while working independent of each other discovered the technique in 1946 (Hornak, 2009). It was not until 1971 that Raymond Damadian demonstrated the usefulness of the MRI in the detection of diseases (Hornak, 2009). Thereafter, a lot of research was conducted leading to discoveries such as: the use of phase and frequency coding by Richard Ernst in 1975; demonstration of the images of the body by Edelstein and co-workers in 1980 resulting in the acquisition of an image within five minutes; and the imaging of blood flow within organs without the use of contrast medium by Charles Dumoulin in 1987 (Hornak, 2009). MRI can also be used in the assessment of the function of certain organs of the body (e.g. the brain). This special technique of MRI is called functional MRI and has numerous applications including mapping the regions of the brain that are responsible for thought and motor control (Hornak, 2009).

MRI is a powerful technique and has been shown to be superior to the computed tomography because of its ability to provide a greater contrast between different soft tissues of the body (Hornak, 2009). In addition, the amount of ionizing radiation emitted by an MRI machine compared to a CT scanner is minimal and as such patients or subjects are not exposed to hazards of ionizing radiation (Hornak, 2009).

1.5 Reasons for the current study

To date, no studies have been conducted to assess the usefulness of fragments of the femur in the estimation of stature in any South African population group even though it is the most often used long bone for stature estimation in the intact state since it bears a constant relationship to stature (Feldesman and Lundy, 1988). Also, none of the metatarsal bones have been used for stature estimation in South Africa. While these skeletal elements can be easily measured using advanced technology such as Magnetic Resonance Imaging, no previous attempt has been made to assess the potential benefit of this technique in stature reconstruction. More importantly, since Fully's method remains to date the only reliable method for estimation of stature in South Africa, and since it has been suggested that Fully's soft tissue correction index might be erroneous, MRI can be used to evaluate the reliability of previously derived soft tissue correction indices and recalculate a new soft tissue index for the indigenous South African male population group if necessary.

1.6 Objectives of the study

It is therefore the aim of this study to:

1. Derive regression equations for the estimation of stature of indigenous South Africans using selected measurements of fragments of the femur;
2. Test the validity of the equations derived in (1) on a sample of South Africans of European descent and derive regression equations for estimation of stature from measurements of fragments of femur of South Africans of European descent;
3. Compare the accuracy of the direct and indirect methods of stature estimation from fragments of the femur;

4. Derive regression equations for stature estimation from lengths of metatarsal bones of South Africans of European descent and indigenous population groups;
5. Calculate new soft tissue index for estimation of living stature in indigenous South African males using MRI.

1.7 Hypotheses of the study

In order to investigate the above listed objectives, the following working hypotheses were proposed:

1. There is significant positive correlation between stature and measurements of fragments of the femur;
2. The correlation between stature and lengths of metatarsals are significantly positive;
3. The accuracy of regression equations from measurements of metatarsals are higher than those of fragments of femur;
4. The previously derived soft tissue correction indices are not applicable to indigenous South African population groups.

Chapter Two

Literature Review

2.1 Methods of stature estimation

According to Sjøvold (2000), three different methods are widely used for stature estimation. These are: (a) the anatomical method; (b) the long bone length/stature ratio; and (c) the mathematical method.

2.1.1 The anatomical method

This involves the use of all components of the skeleton that contribute towards the estimation of stature. Dwight in 1899 was credited with the first attempt at using this method for stature reconstruction. According to Lundy (1983a), Dwight laid down complete skeletons on a table and attempted to join the different components together with clay which was suppose to represent intervertebral discs and cartilages between joints. The entire skeleton was then measured to give an estimate of living stature (Lundy, 1983a). This method is flawed by the arbitrary manner in which the curvature of the spine and height of the hip amongst others were accounted for (Porter, 2002). Also, since this procedure does not take into account soft tissue factors such as the thickness of the scalp and sole of the foot, it may not be regarded as being entirely accurate. In an attempt to improve on this method, Fully (1956) introduced new techniques in measuring the different components of the skeleton that contribute towards stature and also calculated soft tissue correction factors for different ranges of skeletal height.

The procedure as detailed by Fully (1956) has since been widely accepted, and the anatomical method is often referred to as the Fully's method. In May 1955, the Minister of war veterans and war victims in France requested that all French citizens that were buried at a concentration camp in Mauthausen (Austria) should be identified and returned back to France. Fully was involved in this assignment whereby 1846 corpses were exhumed from Mauthausen and an additional 1319 from a neighboring cemetery at Gusen (Fully, 1956). Quite a number of the skeletonised remains were identified by number plates that were attached to their wrists. These numbers were then compared with the record of individuals as contained in the archives at the cemeteries. A further confirmation was carried out by information obtained from family members and other documents that were found at the concentration camps.

Fully (1956) selected 102 complete skeletons of males of different European nationalities. On each complete skeleton, he measured appropriate dimensions of the skull, vertebrae, femur, tibia, talus, and calcaneus. These measurements as directed by Fully (1956) and Fully and Pineau (1960) are: (a) Basi-bregmatic height of the skull; (b) Anterior body heights of vertebrae C2 to S1; (c) Physiological length of the femur; (d) Medial condylomalleolar length of the tibia; and (e) The articulated height of the talus and the calcaneus. The sum total of these measurements is termed the total skeletal height (TSH).

2.1.1.1 Soft tissue correction factor

In order to account for the thickness of the scalp, intervertebral discs and soft tissue of the sole of the foot, Fully (1956) devised correction indices. He calculated skeletal height for each complete skeleton (as described in the preceding section) and subtracted this from the documented height as contained in the archives of the cemeteries for 60 of the 102 subjects studied. The mean of the difference, termed the correction index, was subsequently calculated.

Based on this calculation and modifications, he instructed that for skeletal heights of 153.5 cm or less, 10.0 cm should be added. Skeletal heights of between 153.6 cm and 165.4 cm would require 10.5 cm to be added as a soft tissue correction factor, while 11.5 cm was suggested for skeletal heights of 165.5 cm and above. The resultant height after the addition of the correction index gives an estimate of the living stature (ELS). These correction indices were then applied to the test sample of 42 skeletons with a favorable outcome.

2.1.1.2 Correction factor for age

Age related loss in stature is another factor that is corrected for in the estimation of living stature (Trotter and Gleser, 1951; Hertzog *et al.*, 1969; Galloway, 1988; Cline *et al.*, 1989; Giles, 1991). In 1951, Trotter and Gleser observed that a decrease in stature starts at the age of 30 years and this decrease is not sex dependent. Trotter and Gleser (1951) recommended that 0.06 cm per year above the age of 30 years should be subtracted from the estimated living stature. Galloway (1988) disagreed with this recommendation and proposed 45 years as the age of onset for age-related decrease in stature. He concluded that 0.16 cm per year above the age of 45 should be subtracted from the estimated living stature.

Cline and co-workers (1989) used longitudinal changes in the stature of a sample of adults from households in Tucson, Arizona. Cline *et al*. (1989) observed that while decreases in stature with age begins earlier in males, a greater rate of decline in stature per year was observed in females due to a higher incidence of osteoporosis and its associated complications in women. Cline *et al*. (1989) presented sex specific equations based on age to account for the observed decline in stature. In 1991, Giles published a table of estimates that should compensate for age-related decreases in stature for individuals aged between 46 and 85 years. His study showed that the use of the correction factor proposed by Galloway (1988) overestimates stature loss but it is in agreement with the study by Cline *et al*. (1989) regarding the sex specificity of this factor. Since all the aforementioned studies were conducted in the United States on skeletons and subjects of American origin, there is still uncertainty about the general applicability of these factors on other population groups.

2.1.1.3 Studies on stature estimation using Fully's (1956) method

Even though the anatomical method of stature estimation is complex, time consuming and requires the presence of all components of the skeleton that constitute stature, some authors consider it as the best and the most accurate method for the estimation of living stature {Stewart in 1979 cited by Raxter *et al*. (2006); Lundy,1985, 1988; Ousley, 1995). It has the added advantage of not been sex and population specific regarding the estimation of stature (Tatarek and Sciulli, 2005). It has been used to formulate regression equations in paleoanthropological (Jungers, 1988; Sciulli *et al.,* 1990; Sciulli and Giesen, 1993; Formicola and Franceschi, 1996) and forensic studies (Lundy, 1983b; Lundy and Feldesman, 1987; Dayal, 2002; Bidmos and Asala, 2005; Bidmos, 2006; Ryan and Bidmos, 2007; Chibba and Bidmos, 2007). To date it remains the only usable method for formulation of regression equations for estimation of stature in South Africa.

In 1983, Lundy made the first attempt in South Africa at using this method for derivation of regression equations for estimation of stature using long bones of the upper and lower limbs. The need for the use of this method was borne out of the fact Lundy (1983a) observed that most cadaver lengths as documented in the catalogue of the Raymond A. Dart Collection of Human Skeletons were unreliable. On each of the 356 skeletons of indigenous South Africans that constituted his studied sample, Lundy (1983a) followed the instructions of Fully (1956) as mentioned in section 2.1.1 above. In addition, Lundy (1983a, b) measured the maximum length of the humerus, radius, ulna, femur, tibia and fibula. The calculated total skeletal height was then regressed on lengths of long bones of the upper and lower limbs. Dayal (2002) conducted a similar study on South African whites.

Bidmos and Asala (2005) also used the Fully's method (1956) in the estimation of skeletal height of 156 skeletons of indigenous South Africans. Bidmos and Asala (2005) formulated regression equations for stature estimation from nine measurements of the calcaneus. Their selection of the calcaneus over other tarsal elements was based on the fact that the calcaneus is a compact bone that is often recovered intact in forensic and archaeological cases. Its forensic application in South Africa at that time had not been investigated. Subsequently, stature estimation studies using measurements of the calcaneus of South Africans of European descent (Bidmos, 2006b), the skull of indigenous South Africans (Ryan and Bidmos, 2007) and fragments of the tibia of South Africans of European descent (Chibba and Bidmos, 2007) all utilized the Fully's method (1956) in the initial assessment of skeletal height.

2.1.1.4 Reliability of Fully's method in the estimation of stature

Lundy (1985, 1988), Formicola (1993), and Formicola and Franceschi (1996) reported that Fully's technique (1956) is a very accurate method in the estimation of stature. In 1988, Lundy used Fully's method (1956) in the estimation of stature of three white male United States military officers whose skeletal remains were returned after the Vietnam War. Lundy (1988) compared their documented living stature (from antemortem data) with (1) living stature using Fully's method (1956) and (2) living stature using Trotter and Gleser's (1958) equations. Lundy (1988) concluded that while the Fully's method (1956) is as accurate as the use of Trotter and Gleser's

(1958) equations in two of the cases, it provided a more accurate result in one of the three cases thereby confirming his earlier observation on the reliability of the Fully's method.

Tatarek and Sciulli (2005: page 74) observed that "one drawback of the Fully method is the assumption that the correction for soft tissue thickness, which is derived from French males, is applicable to individuals from all populations". This observation was put to test by Bidmos (2005b) who used a larger sample size (156 complete skeletons) obtained from the Raymond Dart Collection to test the reliability of the Fully's (1956) method. He (2005b) observed marked differences between estimates of the living stature from documented cadaver length (ELS_{max}) and estimates of living stature from the use of Fully's method (ELS_{Fully}) in the indigenous South African population (ISA) groups studied. A similar observation was made in the South Africans of European descent (SAED) population groups, but these differences were not as marked as that observed in the ISA groups.

Bidmos (2005b) proposed that these differences might be due to the influence of the soft tissue correction factor. It seemed that these correction factors worked better for the SAED samples. Since these factors were originally derived from French samples, to which the SAED is possibly closer to genetically than to ISA, these correction factors may indeed be population specific. A similar study was conducted by Raxter and co-workers in 2006 using materials obtained from the Terry Collection housed in the Smithsonian Institute, Washington DC. Raxter *et al.* (2006) supported Bidmos' (2005b) observation that Fully's method (1956) underestimates stature but could not verify population specificity of soft tissue correction factors.

As mentioned in section 2.2.1.3 above, the anatomical method has the disadvantage of being time consuming and complicated (Lundy, 1988) and also requires the presence of a complete skeleton. Since all the bones that constitute stature are not always available in forensic cases for stature estimation, the anatomical method is therefore not universally applicable.

2.1.2 The long bone length/stature ratio

Krogman and İşcan (1986) credited Rollet in 1888 with the first attempt at publishing tables that show the relationship between stature and long bone lengths. Rollet measured the maximum length of long bones of the upper and lower extremities namely humerus, radius, ulna, femur, fibula and tibia of 100 French subjects equally distributed by sex. In 1892, Manouvrier excluded individuals above the age of 60 years from Rollet's data and presented new tables for French men (N=24) and women (N=25). While Rollet and Manouvrier presented tables from which the stature of an individual with a given long bone length could be read, it was Hrdlička in 1939 who presented long bone/ stature indices using skeletons of American Whites and Blacks obtained from a dissecting room population (Krogman and İşcan, 1986).

Investigations by Feldesman and Lundy (1988) and Feldesman *et al.* (1989) showed that femur/stature ratio is a constant factor which is neither sex nor population dependent. In a larger study that involved 13, 149 contemporary humans from 51 different population groups, Feldesman *et al.* (1990) confirmed the universal application of the ratio. They (1990) concluded that the mean ratio of femur to living stature is 26.74% in all population groups. This means that an individual with a femur length of, for example 40cm, will have a stature of 40 x 100/ 26.74 = 150cm. In a comparison of the efficacy of the ratio with published regression equations, Feldesman *et al.* (1990) observed that while the ratio is more accurate than regression equations in the estimation of stature of Vietnam veterans and a single Akka pygmy, it is less accurate when applied to a sample of South African "Blacks".

Meadows and Jantz (1995) reported that the femur/ stature ratio is a biased estimator of stature and its value varies with stature. Since it is regarded as a special case of classical calibration (Konigsberg *et al.* 1998), there is the tendency of taller individuals with relatively longer femora to be overestimated (Meadows and Jantz, 1995) and shorter individuals to be underestimated (Sjøvold, 2000). Hens *et al.* (1998: pages 409-410) summed up their assessment of femur/ stature ratio as an estimator of stature thus: "We cannot generally recommend the femur/stature ratio as an estimator, because it assumes isometry both within the reference sample and for the isolated femur. This is a strong assumption and one that we suspect has relatively little empirical support, particularly across primate taxa".

2.1.3 The mathematical method

In 1899, Pearson disagreed with Manouvrier's reason for the exclusion of older skeletons from Rollet's original data and thereafter used the same data in the development of the most widely used statistical theorem in stature reconstruction termed regression analysis (Krogman and İşcan, 1986). Porter (2002: page 21) noted that Pearson "applied the rigorous approach of a mathematician, appreciated the frailty of the data and the need to measure uncertainty and was the first of many to counsel 'very great caution' when applying stature formulae derived from a modern reference population to an 'ancient race'". Regression analysis formed the basis for the mathematical method of stature estimation and involves the derivation of regression equations from components of the skeleton and percutaneous bones. These equations show the linear relationship between different dimensions of bones and stature.

In addition to the femur/ stature ratio, four other statistical methods of stature estimation using regression analysis are described in the literature. These are: (i) regression of stature on a long bone length; (ii) regression of long bone on stature also called the classical calibration; (iii) major axis regression of stature on long bone length; and (iv) reduced major axis regression of stature on long bone length. A detailed account as well as discussion of the advantages, disadvantages, applicability and reliability of these methods can be found in the works of Hens *et al.* (1998) and Konigsberg *et al.* (1998). A brief account of some of the studies that have been conducted on stature estimation worldwide using regression analysis is given below. These studies have been classified based on type of bones and parts of the body for ease of reference and description, and should not be construed as order of importance.

2.1.3.1 Intact long bones

Regression equations presented by Pearson for French men and women using Rollet's data have since been discarded because of the small sample size from which the equations were derived and also due to the shortness of the stature of the studied subjects (Porter, 2002). However, the principle laid down by Pearson in the reconstruction of stature was applied in a 1929 study by Stevenson on a group of 48 Chinese male cadavers (Trotter and Gleser, 1952a). Stevenson's regression equations were applied on Rollet's data, while the reliability of Pearson's equations was assessed on the studied Chinese subjects. The result of the analysis by Stevenson confirmed Pearson's earlier caution on population specificity of regression equations (Trotter and Gleser, 1952a). Similar equations were derived in subsequent studies by Breitinger in 1937 on living Germans and Telkkä in 1956 on Finnish cadavers (Trotter and Gleser, 1952a).

In 1951, Dupertuis and Hadden presented long bone/stature ratios for each of the humerus, radius, femur and tibia for Americans using a sample of cadavers that were derived from the Hamann-Todd Collection. In addition, Dupertuis and Hadden (1951) calculated regression formulae for their sample based on measurements of long bones of the right side only. They (1951) noted that a combination of two or more long bones should give a better prediction of stature and recommended the calculation of stature thereof when ever possible.

Trotter and Gleser (1952a) conducted arguably the biggest study on stature reconstruction to date when they measured the maximum length of humerus, radius, ulna, femur, tibia and fibula and subsequently formulated sex and population specific regression equations for the estimation of stature of American "Whites" and "Blacks". Their sample consisted of skeletons that were derived from the Terry Collection (255 White male, 63 White female, 360 Black male, 177 Black female) and the remains of American military personnel (1115 White male, 85 Black male) of the Second World War.

In 1958, Trotter and Gleser revised these equations for two reasons. Firstly, the availability of a large number of skeletons of American White (N=4672) and Black (N=577) soldiers that died during the Korean War between 1950 and 1953, were available and were expected to give more accurate regression formulae for these two population groups. Secondly, there was a need to obtain regression formulae for Americans of Mexican (N=112), Puerto Rican (N=64) and Mongoloid (N=92) origin.

In this study they observed an increase in stature compared to their 1952 study (Trotter and Gleser, 1952a) and advised that regression equations should be derived at opportune intervals to take account of secular trend. These two classical studies in stature reconstruction are not without limitations, which were identified by the authors as well as subsequent researchers (Porter, 2002). Since then regression equations for stature estimation from length of long bones have been presented by Allbrook for British and East Africans in 1961, Olivier for French men and women in 1963, Yung-hao *et al*. for Chinese in 1979, Ċerný and Komenda in 1982 for the Czechs to mention a few (Krogman and İşcan, 1986). Some of the equations and tables are published in a review paper on estimation of stature by Sjøvold (2000).

The first study on stature reconstruction in South Africa was carried out by Lundy (1983a). He (1983a, b) presented regression equations for the estimation of skeletal height of South African “Blacks” from measurements of long bones of the upper and lower extremities. In 1987, these equations were revised because “ the computer program Lundy used to compute the regression equations handled missing values in a manner different from what he had expected” (Lundy and Feldesman, 1987; page 54). Lundy and Feldesman (1987) concluded that the revised equations should offer physical and forensic anthropologists a high degree of precision in the estimation of stature of South African “Blacks” from lengths of long bones of the upper and lower extremities. Also, they (1987) warned against the use of these equations on other population groups. In response to this advice, Dayal (2002) used the same technique and similar measurements of the long bones of the upper and lower limbs as well as segments of the vertebral column for the derivation of regression equations for estimation of stature of South African “Whites”. The standard errors of estimate for Dayal’s (2002) equations are slightly lower compared to those presented by Lundy and Feldesman (1987) which therefore indicates a better accuracy of Dayal's (2002) equations.

Due to the lack of available standards for Portuguese, De Medonça (2000) measured the length of 100 male and 100 female cadavers that were autopsied at the Medico-Legal Institute of Oporto. Living stature for each of the cadaver was calculated by subtracting 2cm from the measured cadaver length as suggested by Trotter and Gleser (1951). Regression equations were presented for living stature estimation from full (or maximum) length of the humerus, physiological length of the femur and maximum length of the femur. The presented standard error of estimate ranged between 5.92 and 8.44 cm. Similar studies were conducted on contemporary Bulgarian (Radoinova *et al.*, 2002) and Polish (Hauser *et al*., 2005) population groups.

Hauser *et al*. (2005) studied 91 human bodies (71 males, 20 females) from which regression equations were formulated from cadaver length (independent variable) and maximum length of the femur (dependent variable). While the size for the female sample was too small to allow for any reasonable conclusion, the authors still presented regression equations for women. In an attempt to compensate for the small female sample size, they combined data for males and females and thereafter derived a single combined equation for both sexes. This is a contradiction to the general principle of regression analysis as laid down by Pearson in 1899 and supported by numerous researches over a period of more than 100 years regarding population and sex specificity of regression equations. Even though the authors recommended the use of their equations for reconstruction of living stature, they failed to heed the advice of Trotter and Gleser (1951) regarding the conversion of cadaver length to living stature. They also did not give any reason for their assumption that equates cadaver length with living stature. The possible explanation for this assumption was given in the work of Petrovečki *et al*. (2007).

It is unethical to cause unnecessary mutilation to cadavers or expose healthy individuals to radiation without medical reasons in Croatia (Petrovečki *et al*., 2007). For these reasons, Petrovečki *et al*., (2007) designed their research technique in consonance with a previous one on a contemporary Spanish population group by Munoz *et al*. (2001) that involved the use of cadaver length and radiographically determined length of long bones of the upper and lower limbs in stature reconstruction. Petrovečki *et al*., (2007) conducted their research on 21 male and 19 female cadavers with mean ages of 60 and 67 years respectively. The length of the humerus, radius, ulna, femur, tibia and fibula of each cadaver was measured with a ruler on antero-posterior radiographs while the length of each was measured on a special tool. They argued that since the measurements of cadaver lengths in their study were carried out within 24 hours of death, the expected significant loss of water and increased tonicity of muscles responsible for increased cadaver length could not have taken place. Therefore, the measured cadaver lengths could be presumed to be the same as living stature and there was no need for correction for living stature as suggested by Trotter and Gleser (1951). The humerus and the tibia presented with the best correlation in females ($r = 0.792$) and males ($r = 0.891$) respectively. These findings contradict the results of most studies on stature in which the femur showed the highest correlation with stature (e.g. Trotter and Gleser, 1952a,b, 1958; Lundy 1983a, b; Lundy and Feldesman, 1987; Munoz *et al*., 2001; Dayal, 2002).

Long bones of the upper and lower extremities continue to attract the attention of forensic and physical anthropologists in the formulation of population and sex specific regression equations for stature estimation (Mall *et al*., 2001; Ross and

Konigsberg, 2002; Duyar and Pelin, 2003; Celbis and Agritmis, 2006). Since long bones are often recovered in various states of fragmentation in forensic and archaeological practice, the use of measurements of fragments of long bones in the estimation of stature became necessary.

2.1.3.2 Fragments of long bones

In 1935, Gertrude Müller introduced a new technique in stature reconstruction that involves the indirect estimation of stature from fragments of long bones (Steele and McKern, 1969; Steele, 1970). She identified landmarks on 100 humeri, 50 radii and 100 tibiae of Germans from which she described six, four and seven segments on the humerus, radius and tibia respectively (Steele and McKern, 1969; Steele, 1970). Thereafter, the percentage contribution of each segment to the maximum length of the long bone was calculated. It was therefore possible to estimate the maximum length of these bones from any of their measured segments by using the calculated percentages. The corresponding stature for the estimated bone length can be subsequently read off on previously published stature/ bone length tables.

Steele and McKern (1969) identified two limitations of Müller’s study. First, the femur which is regarded as the singular bone with the highest correlation with stature was omitted. Second, the calculated percentages were simple and involved the use of a single segment at a time. In other words, Müller failed to present percentages for combinations of segments which may provide a better accuracy for maximum bone length estimation compared to the use of an individual segment.

As a result, Steele and McKern (1969) substituted the femur for the radius in their study which was conducted with the aim of refining Müller’s technique by using a more advanced statistical method. Their sample consisted of skeletons of 117 adult individuals from a prehistoric American population (American Indians or Amerindian) recovered from archaeological sites in northeastern Arkansas. They identified five, four and five segments on the humerus, femur and tibia respectively. The mean percentage contribution of each segment to maximum length of long bone as suggested by Müller was calculated. In addition, mean percentages were calculated for combinations of segments of these bones. They (1969) proved that a combination of segments of any of the studied long bones presented with higher accuracy in the estimation of the maximum length of the long bone compared to the use of an individual segment. By further subjecting their data to the least squares method of regression analysis, they concluded that the presented equations will provide a better estimate of maximum long bone length compared to the simple percentage method.

Steele (1970) conducted a similar study using the same skeletal elements (i.e. humerus, femur and tibia). His sample consisted of modern American population groups of European and African descent obtained from the Terry Collection housed in the Smithsonian National Museum of Natural History. He derived regression formulae for the estimation of maximum length of these bones from measurements of their segments (Steele, 1970). An estimate of the living stature can be calculated by substituting the estimated maximum length of the specific long bone into the appropriate equation of Trotter and Gleser (1958). Mysorekar *et al.* (1980, 1984) used the same technique as suggested by Steele and McKern (1969) and Steele (1970) in the estimation of maximum length of radius, ulna, femur and tibia from measurements of their segments in an Indian sample. The major limitation of this technique, which Steele (1970) also attested to, is the difficulty encountered in the identification of the exact location of important anatomical landmarks.

Using the humerus as an example, Steele (1970: page 87) conceded that it is difficult to measure "…the point of greatest narrowing at the middle of the diaphysis. Although this narrowing can be related to a point, posterolaterally in the radial groove where the lateral supracondylar ridge becomes indistinct, in practice the point proved impossible to locate with sufficient constancy to give useful results". Simmons *et al*. (1990) presented a new method of estimating stature from fragments of a long bone because the techniques for delineating segments of this bone as suggested by Steele and McKern (1969) and Steele (1970) were not easily reproducible as mentioned above.

Simmons *et al.* (1990) used seven standard measurements of femur obtained from the Terry Collection in the derivation of equations for estimation of maximum length of femur and stature. De Medonça (2000) even though aware of Simmons *et al*. (1990) method attempted to reconstruct the maximum length of the humerus, ulna and tibia by using Steele's (1970) technique. The standard errors of estimate obtained from the presented equations were high thereby rendering the derived equations non-usable (De Medonça, 2000). De Medonça (2000) concluded that efforts should be directed towards the use of Simmons *et al*. (1990) method but he favoured the use of longitudinal over transverse measurements of long bones.

Holland (1992) also used standard measurements of the proximal part of the tibia in the derivation of regression equations for Americans. These measurements included the length and breadths of the medial and lateral condyles of the tibia and the biarticular breadth of tibial condyles. The biarticular breadth displayed the highest correlation (0.81) with stature. A similar study was conducted in South Africa by Chibba and Bidmos (2007). In addition to the lengths and breadths of the medial and lateral condyles of the tibia, Chibba and Bidmos (2007) also measured the distal and proximal breadths of the tibia from which regression equations were derived for the estimation of skeletal height and maximum length of the tibia. While the correlation between stature and these measurements were moderate (0.54 – 0.71), the standard error of estimate from the derived equations were high (males: 6.52 – 6.71; females: 5.20 – 5.94) which indicated a low accuracy compared to intact long bones.

2.1.3.3 Hand and foot bones

Musgrave and Harneja (1978) described a new method for the estimation of living stature from length of the metacarpal bones. Their sample consisted of 100 male and 46 female mainly white British patients who attended the Bristol Royal Infirmary with hand injuries. The physiological length of each of the metacarpal was measured from the radiograph of the injured hand in each patient. The first and second metacarpals presented with the highest correlation with living stature in male and female subjects respectively. The validity of the derived equations was assessed on a sample of ten individuals who were part of the original sample used in the derivation of the equations. Expectedly, the reliability of the tested equations was found to be acceptably high. Musgrave and Harneja (1978) further subjected their equations to more rigorous testing by using an independent sample which consisted of skeletal remains of modern and fossil subjects. Again, the equations were found to be accurate in the estimation of the stature of these skeletal remains.

The method used in this assessment is, however, faulty for two reasons. First, even though none of the skeletal remains of the modern man used in this analysis was from the United States of America, the living stature of each of the subject was estimated with the use of Trotter and Gleser’s (1958) equations which were originally formulated for Americans. This is contrary to the generally accepted principle in physical anthropology that regression equations should be limited to the population group from which they were derived. Secondly, since Musgrave and Harneja's (1978) equations were derived from a sample that was predominantly British, their applicability to two illegal immigrants believed to be of Pakistani or Indian origin and a classical Greek from Eritrea forming part of the modern human subject in their independent sample is questionable. The reliability of these equations should have been assessed with an independent sample consisting of British skeletal remains.

There is a growing interest in the forensic application of the metacarpal bone with respect to sex determination (Stojanowski, 1999; Zanella and Brown, 2003; Case and Ross, 2007). However, the only other known published work on the use of metacarpal bone for stature estimation was conducted by Meadows and Jantz (1992) using a larger sample size of skeletal materials (n= 212) obtained from the Terry Collection housed in the Smithsonian Institute, Washington DC. Meadows and Jantz (1992) obtained regression equation for stature estimation using midline length of each of the five metacarpal bones of both hands, and they obtained higher correlation coefficient for the derived equations for males (0.565 – 0.828) compared with that presented in an earlier study by Musgrave and Harneja (1978); however, the correlation is similar for female samples in both studies (0.61 – 0.84 for Musgrave and Harneja, 1978; 0.61 – 0.79 for Meadows and Jantz, 1992). In assessing the reliability of each equation on a living sample of American males, Meadows and Jantz (1992) reported that with the exception of metacarpal 1, equations derived for metacarpals can provide a reliable estimate of stature in the absence of intact long bones.

The metacarpals are the only set of hand bones that have been used for stature estimation. In the foot, however, measurements of metatarsals (Byers *et al*., 1989), talus and calcaneus (Holland, 1995; Bidmos and Asala, 2005; Bidmos, 2006b) have been used for this purpose. It is well documented that numerous studies have been conducted on the morphology of metatarsals from clinical and paleoanthropological perspectives. Zipfel (2003) provided a detailed account of these studies in his work on "Selected aspects of metrical and morphological variation in metatarsals". He concluded that the influence of modern lifestyle is the singular most important factor that could explain the variation in the morphology of metatarsal bones between pre-pastoral and modern human subjects studied. Interestingly, few researchers have investigated the usefulness of metatarsals for forensic purposes (Byers et al., 1989; Robling and Ubelaker, 1997; Case and Ross, 2007).

Byers *et al*. (1989) made the first and only attempt to date at using lengths of metatarsal bones for stature estimation. They selected 130 skeletons from both the Terry Collection at Smithsonian Institute and the Maxwell museum of anthropology of the University of New Mexico. There was a preponderance of skeletons of Euro-Americans (n= 108) compared to Afro-Americans (n= 22) in the studied sample. On each of these skeletons, six measurements of the metatarsal bones were used for derivation of regression equations for estimation of stature in African and European Americans. It is worth mentioning that it was Steele (1970) who recommended the need for investigating the usefulness of metatarsals, talus and calcaneus in stature reconstruction. While there was an earlier response to this advice with regards to metatarsals (Byers *et al*., 1989), it was not until 1995 when a similar study was conducted by Holland on the talus and calcaneus.

The calcaneus is the largest tarsal bone in the human skeleton and is able to withstand high tensile forces (Hall and Shereff, 1993) and therefore it has a greater chance of being recovered intact in forensic and archaeological cases compared to long bones. Some measurements of the calcaneus have been shown to be sexually dimorphic in Americans (Steele, 1976), central Europeans (Riepert *et al*., 1996), Italians (Introna *et al*., 1997) and South Africans (Bidmos and Asala, 2003, 2004). Holland (1995) used three measurements on the calcaneus (maximum length, load arm length and posterior length) and one on the talus (maximum length) to obtain regression equations for stature estimation amongst Americans. While echoing the advice of earlier anthropologists like Trotter and Gleser (1952a, 1958), Holland (1995) also cautioned that the applicability of any equations derived should be limited to the population from which they were originally derived.

For this reason, Bidmos and Asala (2005) conducted a similar study on the calcanei of indigenous South Africans that were derived from the Raymond A. Dart Collection of Human Skeletons. This study differs from the earlier one conducted by Holland (1995) for the following reasons. First, nine measurements of the calcaneus were used compared to three that were selected by Holland (1995). Second, Bidmos and Asala (2005) did not assess the usefulness of the talus for the purpose of reconstructing stature. Third, while Holland (1995) regressed cadaver length on the selected measurements of the talus and calcaneus, Bidmos and Asala (2005) used the Fully's method (1956) for skeletal height estimation after which soft tissue correction factors were added in order to obtain living stature.

The regression equations derived by Bidmos and Asala (2005) were tested on an independent sample of skeletons derived from the Raymond A. Dart and Pretoria Collections and were found to be reliable with most equations showing an accuracy of 80% and above at 2 standard error of estimate. However, the application of Holland's (1995) equations to South African samples revealed consistent overestimation of stature which further confirms population specificity of regression equations. In 2006, Bidmos used the same technique as proposed by Bidmos and Asala (2005) for the formulation of equations for stature estimation from the calcaneus of South Africans of European descent (Bidmos, 2006b). The results of the latter study compares well with the previous by Bidmos and Asala (2005).

A cursory observation from the paragraphs above points to the fact that few studies have been conducted using osteometric criteria of individual bones of the hand and the foot. Perhaps, the reason for this may be due to the interest shown by other researchers into using different parameters of the hand and foot (Ozden *et al*., 2005, Kanchan *et al*. 2008; Sen and Gosh, 2008; Zeybek, 2008) for the purpose of estimating stature. Such techniques also involve the use of foot and shoe prints (Jasuja *et al*., 1997; Krishan, 2008a).

2.1.3.4 The skull and vertebrae

Morphological and metrical assessment of the skull for the purpose of estimation of age, determination of sex and population affinity is well documented (e.g. Kajanoja, 1966; De Villiers 1968; İşcan and Steyn, 1999; Loth and İşcan, 2000). In cases when only the skull is available for forensic analysis, the skull should serve as an important skeletal element from which all four biological traits could be extracted; however, an extensive literature search revealed that only a few studies have been conducted worldwide on reconstruction of stature from measurements of the skull. The reason for this is unknown as the skull forms part of the component of the skeleton that constitutes stature.

Chiba and Terazawa (1998) regressed cadaver length on three skull variables namely skull diameter, skull circumference and the sum of the diameter and circumference. They used these measurements to estimate stature for a Japanese sample and observed a low to moderate degree of correlation coefficients (0.32 – 0.53) between stature and measured parameters. The standard error of estimates for presented equations ranged between 6.59 and 8.59. They cautioned that the results of their study are not conclusive since dimensions of the skull may be influenced by age and advised that further study should be conducted to investigate this observation.

In another study, Patil and Mody (2005) used measurements of the skull from lateral cephalometric radiographs for sex determination and stature estimation. They derived a regression equation from the length of the skull which they concluded is very reliable in the estimation of stature (Patil and Mody, 2005). Ryan and Bidmos (2007) investigated the usefulness of six measurements of the skull of indigenous South Africans in the estimation of stature. Their regression formulae were based on total skeletal height as suggested by Fully (1956). Moderate correlation coefficients (0.40 – 0.54) were obtained while the presented standard errors of estimate (4.37 – 6.24) were high compared to that obtained for intact long bones and the calcaneus indicating a low accuracy.

Recently, Krishan (2008b) measured living stature of 996 adult male Gujjars from the northern part of India. This was regressed on 5 cephalo-facial measurements. By using living subjects, Krishan (2008b) deviated from the methods employed in the previous studies on stature reconstruction from measurements of the skull as described above. The horizontal circumference of head (0.781) and maximum head length (0.775) presented with the highest correlation coefficient. The accuracy of the regression equations that were formulated for these two variables are also high as evident from the value of their standard error of estimate (horizontal circumference of head, SEE = 3.726; maximum head length, SEE = 4.136).

Long before researchers contemplated the use of cranial measurements in stature reconstruction (e.g. Fully and Pineau, 1960; Tibbetts, 1981; Lundy and Feldesman, 1987), there has been a considerable amount of interest in the use of the bones of the vertebral column in the estimation of stature. In response to the observation made by Pearson in 1929 {as cited by Tibbetts (1981)}, Fully and Pineau (1960) derived regression equations for stature estimation from measurements of different segments of the vertebral column using skeletons of individuals who were mainly French nationals.

Due to unavailability of data from the vertebral column of African-Americans, Tibbetts (1981) used the same technique as Fully and Pineau (1960) in the formulation of appropriate regression equations for the estimation of stature from a variety of bone-groups of the axial skeleton that consisted of the second cervical through the fifth lumbar vertebra. Tibbetts (1981) concluded that the derived equations could assist in the estimation of stature even though the obtained standard errors of estimate (5.31 – 6.83) are higher than those obtained for intact long bones. Lundy and Feldesman (1988) and Dayal *et al*. (2009) presented regression equations for estimation of skeletal height from the sum of the height of lumbar vertebrae which they termed lumbar spine. The standard error of estimate for males {5.28 for Lundy and Feldesman (1988); 5.54 for Dayal *et al*. (2009)} is higher than that presented for females {4.70 for Lundy and Feldesman (1988); 5.21 for Dayal *et al*. (2009)} in both studies. The correlation between skeletal height and lumbar spine in both studies were also similar {0.54 – 0.62 for Lundy and Feldesman (1988); 0.56 for Dayal *et al*. (2009)}.

Instead of measuring individual bones of the vertebral column and thereafter obtaining the sum of the heights as proposed by Fully and Pineau (1960), Jason and

Taylor (1995) took separate measurements for the cervical, thoracic and lumbar segments of the vertebral column of 167 autopsied cadavers of Americans. The measurements were taken on the anterior surface of the articulated vertebral bodies with due consideration for the curvature of the vertebral column. The regression equation for the combined thoracic and lumbar segment of the African-American female population group produced the best accuracy (standard error of estimate or SEE = 2.60, correlation = 0.823) while the equation for the cervical segment for the White female group was the least accurate (SEE =7.11, correlation = 0.468).

2.1.4 Secular Trend in Stature in indigenous South Africans

In 1966, Wolanski as cited by Tobias (1985: page 347) defined secular trend as a "long term systematic or non-random changes in a wide variety of traits, in successive generations of a population living in the same territories". The term is used in human biology to describe a trend that is slowly ongoing but persistent in nature and can last 100 to 200 years (Tobias 1985). A stature and weight change is one of the ways in which this phenomenon can manifest itself (Tobias 1985). Studies on growth changes and secular trends through measurements of living stature among indigenous South Africans were conducted by Tobias (1990) for more than three decades.

Tobias (1962) conducted the first study that demonstrated the presence of a positive secular trend in an African population when he observed an increasing stature of the Kalahari San (Bushmen). In a series of studies, Tobias (1975, 1985, 1986a, b, 1990, 1992) also observed a negative or absent secular trend amongst indigenous South Africans. He (1990) reported that the mean living stature of 5018 adult ISA males who were measured in 1973 by Professor Seftel of the Department of Medicine of the University of the Witwatersrand "as part of a public health medical examination" (Tobias 1990: page 98) was 168.9 cm. He (1986a) observed that when the subjects were divided into age cohorts and age dependent shrinkage is corrected for, there was an absence of positive secular trend and a tendency towards negative secular trend. He (1986a) calculated the overall decline in height for each decade to be 0.05 cm (Tobias (1986b, 1992).

In contrast to Tobias's (1975, 1986a, 1986b, 1990, 1992) observation, Henneberg and van den Berg (1990) on re-analyzing Tobias (1975) data using regression analysis reported a weak significant positive secular trend in stature of ISA males. They (1990) also observed that the magnitude of the positive trend in ISA males (0.24 cm per decade) is not significantly different from that observed for SAED males (0.59 cm per decade). The trend observed in South Africa for natives who were previously classified by Tobias (1985) as "have little" and SAED ("have-most") is significantly different from that reported for some countries from the Northern hemisphere (Henneberg and van den Berg, 1990).

They (1990) argued that this phenomenon can be explained based on the postulation of Tobias (1985) who suggested that the SAED displayed absence of secular trend because "they have already reached the upper phenotypic limit set by their genetic endowment" (Henneberg and van den Berg, 1990). In addition, the absence of secular trend in the ISA males is as a result of lack of improvement in their standard of living (Henneberg and van den Berg, 1990). Based on the effect of this phenomenon, earlier researchers like Trotter and Gleser (1958) cautioned that regression equations for estimation of stature should be derived at opportune intervals.

Chapter Three

Fragments of Femur in the Estimation of Stature in Indigenous South Africans*

*Bidmos MA 2008 Estimation of stature using fragmentary femora in indigenous South Africans. *International Journal of Legal Medicine* 122(4):293-299………..**Appendix 1**

3.1 Preamble

It is well documented that lengths of long bones of the upper and lower extremities (i.e. humerus, radius, ulna, femur, tibia and fibula) show a high degree of correlation with stature. As a result, regression equations have been derived for the estimation of stature using these skeletal elements in different population groups. However, these bones are sometimes presented to forensic anthropologists in different states of fragmentation thereby making the derived equations unusable. This has necessitated the need to assess the usefulness of measurements of fragments of long bones (e.g. femur) in the estimation of stature. While few studies have reported such equations, which are population and sex-specific, this chapter assesses the usefulness of fragments of the femur of indigenous South Africans in the estimation of stature.

3.2 INTRODUCTION

The estimation of stature and body size is of great interest to forensic and physical anthropologists. A detailed account of the different methods of stature estimation and body size from bones using various techniques is well documented in previous studies by Lundy (1983a), Krogman and İşcan (1986), and Porter (2002). According to Krogman and İşcan (1986), Pearson developed arguably the most used statistical theorems in stature reconstruction termed regression analysis. This theory was used in the derivation of population and sex-specific regression equations for the estimation of stature (Krogman and İşcan, 1986; Porter, 2002). Subsequently, there has been a lot of interest to derive similar equations using intact long bones of the upper and lower limbs in Americans (Trotter and Gleser, 1952; 1958), British and East Africans {Allbrook (1961) cited in Krogman and İşcan, 1986}, South Africans (Lundy, 1983b; Lundy and Feldesman, 1987; Dayal 2002), Portuguese (De Medonca, 2000), Germans (Mall *et al.*, 2001), Bulgarians (Radoinova, 2002) and Turks (Celbis and Agritmis, 2006) amongst others. Attempts were also made to formulate regression equations using measurements of the skull (Chiba and Terazawa, 1998; Ryan and Bidmos, 2007) and other postcranial elements (Byers *et al.*, 1989; Meadows and Jantz, 1992; Holland, 1995; Jason and Taylor, 1995; Bidmos and Asala, 2005; Bidmos, 2006). From the results of all these studies, the femur in the intact state is one of the bones with the highest correlation with stature. It has also been shown to yield the best accuracy in the estimation of stature for any individual skeletal element (Feldesman, 1992).

However, the femur is not always recovered intact in forensic and archaeological cases thereby rendering the equations derived from the whole bone inappropriate for analysis. This has necessitated the derivation of regression equations from fragments of the femur. Steele and McKern (1969) made the first attempt at estimating stature from fragments of the femur using five landmarks from which four segments were delineated. They derived regression equations for the estimation of maximum length of the femur from each of the segments and combinations of these segments using pre-historic American femora obtained from three different sites in Mississippi. Similar equations were also presented for the estimation of maximum length of humerus and tibia from different segments of these bones.

The method of estimating maximum length of the femur from its segments was revised by Simmons *et al.* (1990) because the techniques for delineating segments of this bone as suggested by Steele and McKern (1969) were not easily reproducible. Simmons *et al.* (1990) used eight standard measurements of femur obtained from the Terry Collection in the derivation of equations for estimation of maximum length of femur and stature. Studies have also been conducted on the usefulness of fragments of the upper end of the radius and the lower end of the femur (Mysorekar *et al.*, 1980), segments of the ulna and tibia (Mysorekar *et al.*, 1984) and fragments of tibia (Holland, 1992; Chibba and Bidmos, 2007) in the estimation of stature with different degrees of success.

Since no studies have yet been conducted on the estimation of stature from fragments of the femur in South Africa, this study aimed to derive regression equations for estimation of the maximum length of the femur and stature from fragments of the femur.

3.3 MATERIALS AND METHODS

3.3.1 Materials

Two sets of samples were used in this study. The calibration sample (sample A) consisted of 100 (50 male and 50 female) complete skeletons of indigenous South Africans (ISA). This sample was used in the derivation of regression equations for estimation of the maximum length of femur and stature. The test or independent sample (sample B) of 20 complete skeletons, equally distributed by sex, was used in the assessment of the reliability of the derived regression equations. These skeletal elements were obtained from the Raymond A. Dart Collection of Human Skeletons, School of Anatomical Sciences, University of the Witwatersrand, Johannesburg.

The ISA population group consisted of various tribes including Zulu, Xhosa, Tswana, Sotho, Pedi, Venda to mention a few, but for the purpose of this study, samples were obtained mainly from the Zulu, Xhosa, Sotho and Tswana tribes as they constitute the majority of the skeletons of the ISA population group in the Raymond A. Dart Collection. These four tribes were treated as a single homogeneous group because previous studies have shown that no statistically significant intertribal differences exist in the metrical analyses of skulls (De Villiers, 1968) and postcranial skeletons (Lundy, 1983a).

The ages of individuals whose skeletons form the samples used in this study ranged between 46 and 75 years. Period of death for these skeletons ranged between 1975 and 2000. Complete skeletons comprised of a complete skull, vertebrae, femur, tibia, talus and calcaneus were used. Specimens with missing elements, broken edges and excessive osteophytic lippings were excluded. In cases where extra vertebrae were present, their anterior body heights were included in the calculation of total skeletal height (Lundy, 1983a).

3.3.2 Methods

A simple random sampling technique was used in the selection of skeletal materials because it gives all specimens an equal opportunity of being chosen. Fully's (1956) method was used in the calculation of total skeletal height (TSH). This became necessary as previous studies have shown that documented cadaver lengths in the Raymond A. Dart Collection are not reliable (Lundy, 1983a).

3.3.2.1 Measurements of total skeletal height

The following measurements as described by Fully (1956) and Bräuer (1988) were taken on each complete skeleton:

3.3.2.1.1 Basi-bregmatic height of the skull

This is the distance between bregma (the junction between the sagittal suture and coronal suture of the skull) and the most inferior part of the anterior margin of the foramen magnum (Figure 3.1);

3.3.2.1.2 Anterior body heights of vertebrae C2 to L5

The distance between the most superior and the most inferior points of the anterior aspect of the body of each vertebra (Figure 3.2);

3.3.2.1.3 Anterior body height of S1

The linear distance between the midpoint of the sacral promontory and the horizontal line between the first and the second sacral segments represents the height of the body of S1 (Figure 3.3);

Figure 3.1 Measurement of the basi-bregmatic height of the skull using a spreading caliper. Scale = 5 cm

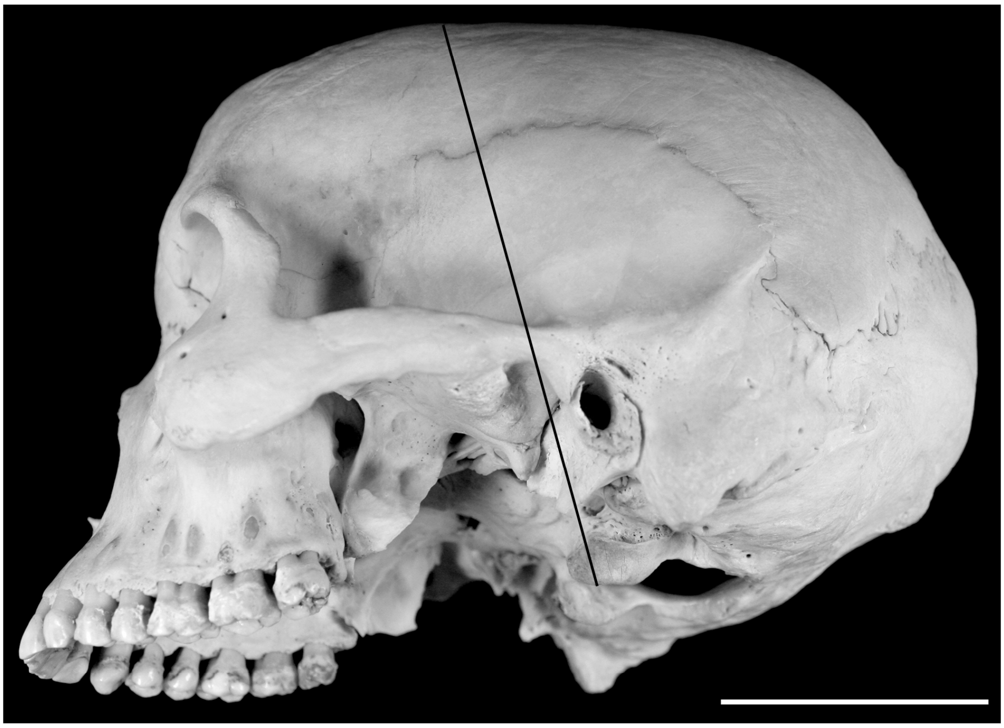


Figure 3.2 Measurement of the anterior body height of the second cervical (A), seventh cervical (B) and tenth thoracic (C) representing the thoracic and the lumbar series. All measurements were taken using the vernier caliper. Scale = 1 cm

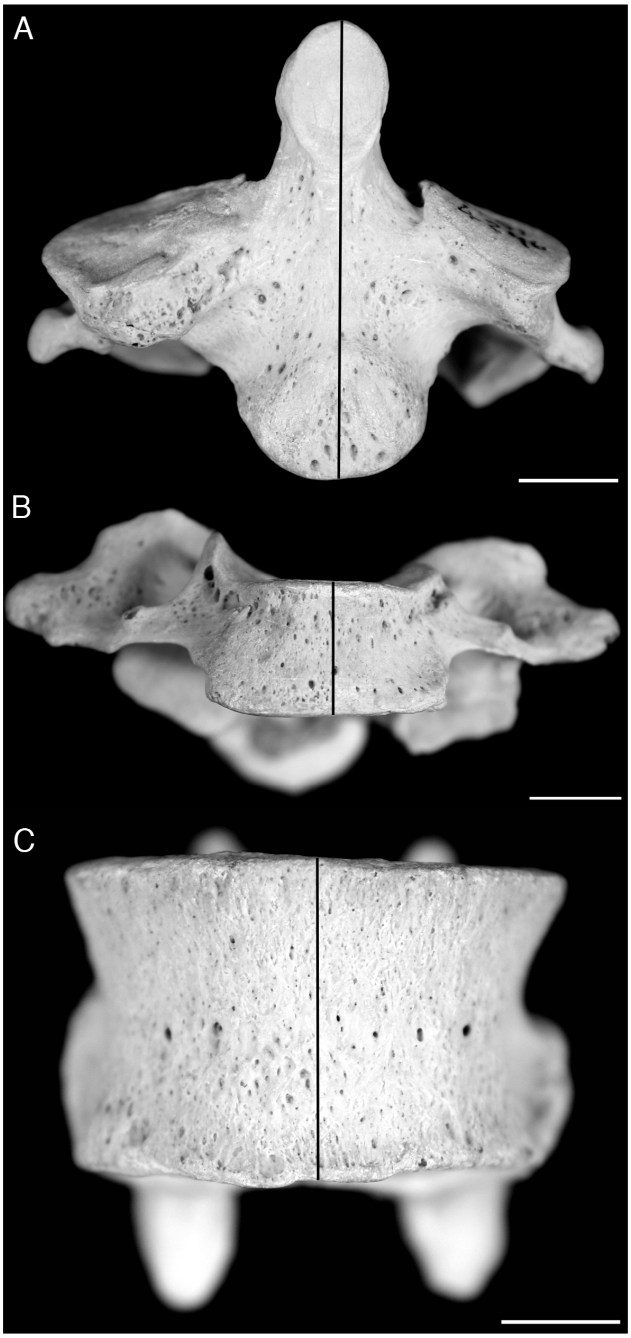
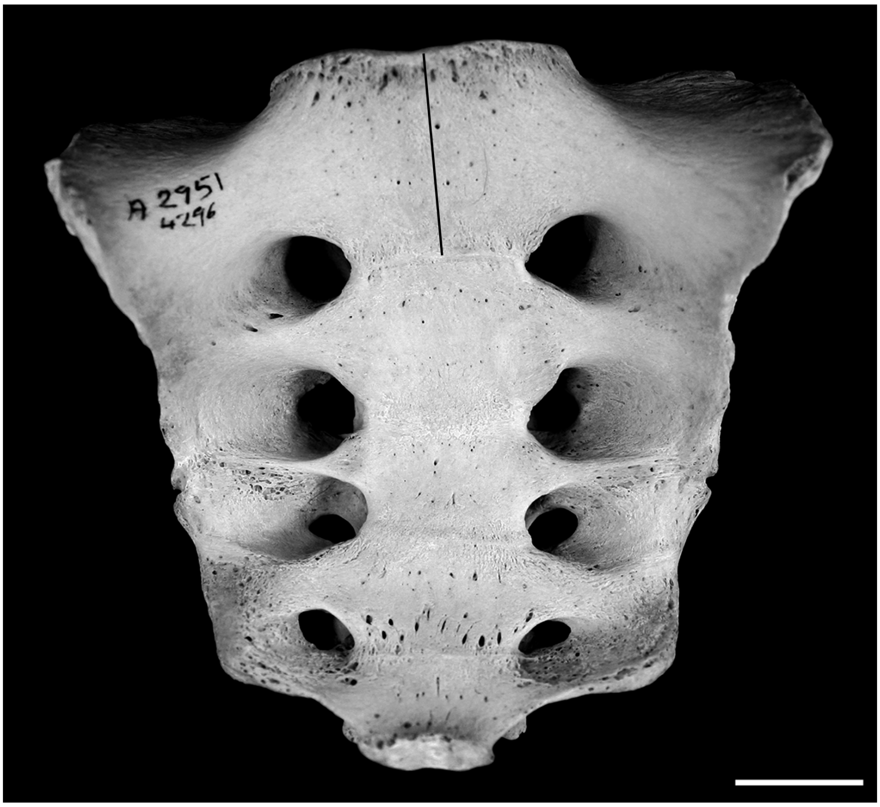

A
B
C

Figure 3.3 Measurement of the anterior body height of the first sacral segment using a sliding caliper. Scale = 2 cm


A 2951
4296

3.3.2.1.4 Physiological length of the femur

This is also referred to as the bicondylar or oblique length of the femur. It is the distance between the most superior point on the head of the femur and an imaginary line that runs across the most inferior parts of the two condyles with the femur in a position that corresponds to that occupied by it in the standing position (Figure 3.4);

3.3.2.1.5 Medial condylomalleolar length of the tibia

The distance between the superior articular surfaces of the condyles and the tip of the medial malleolus represents the maximum length of the tibia (Figure 3.5); and

3.3.2.1.6 The articulated height of the talus and the calcaneus

It is the linear distance from the most superior point of the talus to the most inferior point of the calcaneus (Figure 3.6).

The sum total of these measurements described above (3.3.2.1.1 – 3.3.2.1.6) gives an estimate of the total skeletal height (TSH).

Figure 3.4 Measurement of the physiological length of the femur using an osteometric board. Scale = 2 cm.

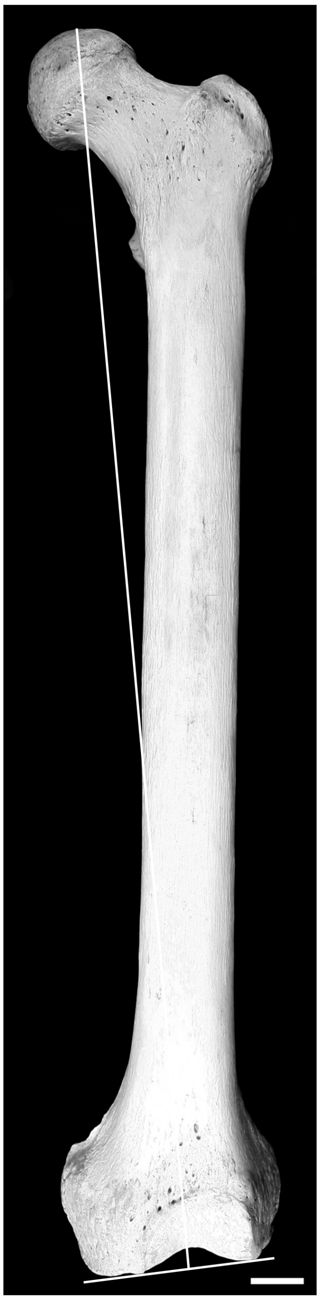


Figure 3.5 Measurement of the condylomalleolar length of the tibia using an osteometric board. Scale = 2 cm.

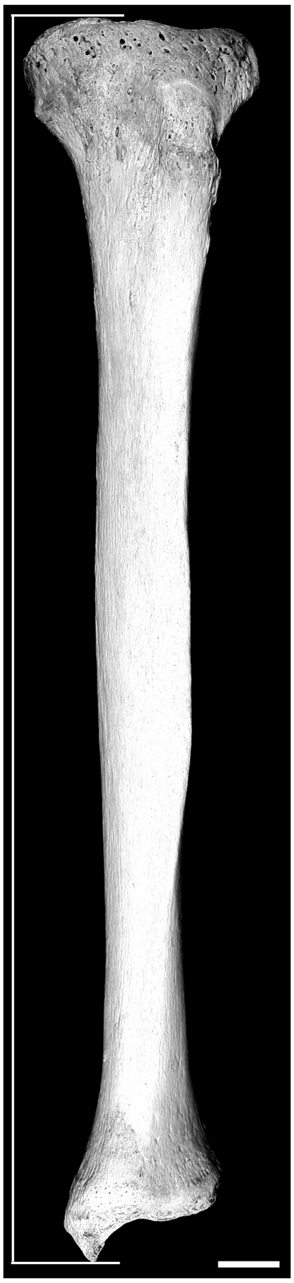


Figure 3.6 Measurement of the talocalcaneal height using the osteometric board

3.3.2.2 Measurements of fragments of femur

In addition to the abovementioned measurements in section 3.3.2.1, seven other measurements were taken on each left femur. They are as described below following the instructions of Bräuer (1988):

3.3.2.2.1 Maximum length of femur (MaxL)

The linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle (Figure 3.7);

3.3.2.2.2 Upper epicondylar length (UEpL) or upper breadth of femur (VHA)

The linear measurement between the most superior point on the fovea capitis of the femur to the inferior aspect of the greater trochanter (Figure 3.8A);

3.3.2.2.3 Vertical neck diameter (VND)

The minimum linear distance between the superior and inferior points on the neck of the femur (Figure 3.8B);

3.3.2.2.4 Bicondylar breadth (BCB)

The linear distance between the medial and the lateral epicondyles of the femur (Figure 3.8C);

3.3.2.2.5 Epicondylar breadth (EpB)

The linear distance between the medial border of the medial condyle and the lateral border of the lateral condyle (Figure 3.8D);

Figure 3.7 Measurement of the maximum length of the femur using the osteometric board. Scale = 5 cm.

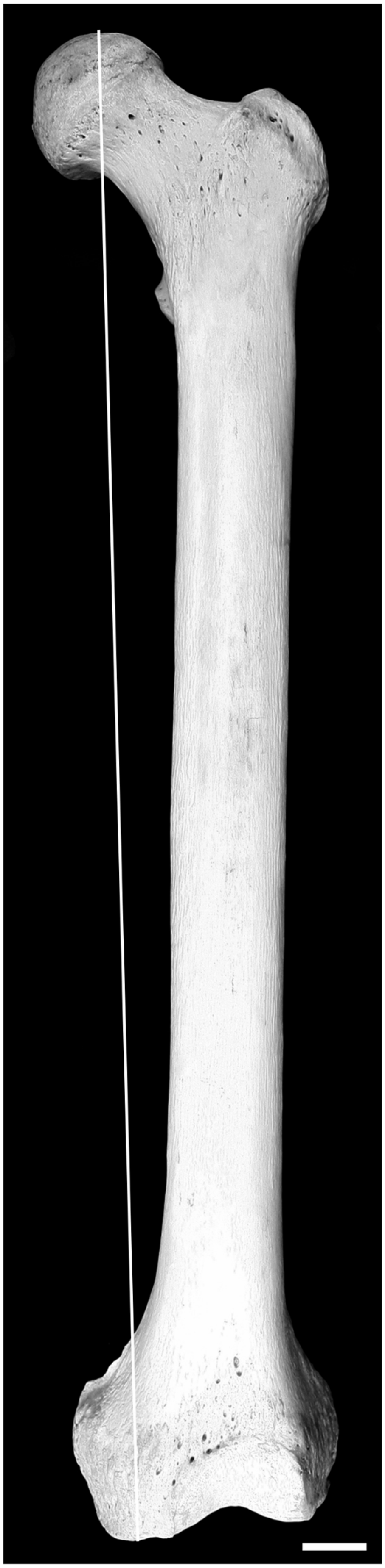


Figure 3.8 Measurements of fragments of the femur: Upper epicondylar length (A); Vertical neck diameter (B); Bicondylar breadth (C); Epicondylar breadth (D); Lateral condylar length (E) and Medial condylar length (F). Scale = 2 cm.


A
B
A 2951
C
D
A 2951
4296
F
E

3.3.2.2.6 Lateral condyle length (LCL)

This is the linear distance on the lateral condyle measured in an anteroposterior direction (Figure 3.8E); and

3.3.2.2.7 Medial condyle length (MCL)

His is the linear distance between the most anterior and the most posterior points on the medial condyle (Figure 3.8F).

The maximum length and bicondylar breadth were measured on an osteometric board while the rest of the measurements were taken using a vernier caliper.

3.3.2.3 Test of Reliability

Lin’s (1989) concordance co-efficient of reproducibility was used in the assessment of the reliability of the measuring technique used in this study and 10 complete skeletons were used for this purpose. After establishing that the measuring technique was adequate, data were collected and placed into excel spreadsheets and statistical analysis was carried out on the male and female groups separately using the ‘Statistix’ program.

3.3.2.4 Analysis of data

Descriptive statistics including means and standard deviations were obtained for both sexes. Normality of distribution of data for both sexes was also verified by comparing the histograms of each femoral measurement with the normal distribution curve. Thereafter, univariate and multivariate regression analyses were performed.

Firstly, TSH was regressed on individual measurements and combinations of measurements of the femur. Secondly, maximum length of femur (MaxL) was regressed against individual measurements and combinations of measurements of the femur. From these analyses, the correlation coefficient (r), unstandardized coefficient, constant and standard error of estimate (SEE) were obtained. Regression equations were formulated from these coefficients and constants.

Femoral measurements from each of the specimens in the test sample were substituted separately for males and females into appropriate regression equations derived in this study for estimation of (a) maximum length of femur and (b) stature. In order to assess the reliability of each regression equation in the estimation of stature, the number of specimens with calculated total skeletal height (using Fully's method) falling within 1 and 2 standard errors of estimation of the estimated skeletal height (using derived regression equation from the present study) is expressed as a percentage of the total number of specimens in the tested sample. A similar procedure was also performed for regression equations derived for estimation of maximum length of femur.

3.4 RESULTS

3.4.1 Descriptive statistics

The means and standard deviations of femoral measurements and total skeletal height (TSH) are presented in Table 3.1. Males consistently showed significantly ($p<0.001$) higher mean values for all the measurements compared with females. The mean ages for males and females were 41.8 and 46.5 years, respectively.

3.4.2 Regression analysis

All measurements of the femur showed a positive correlation with TSH. The medial condyle length showed the highest correlation (0.74) with TSH (Table 3.2) in the male sample while the other measurements displayed moderate correlation with TSH (Table 3.2). However, all femoral dimensions in the female sample displayed high correlation with TSH (Table 3.2).

Table 3.3 shows equations that can be used in the estimation of TSH from measurements of the femur. The equations are arranged in increasing order of correlation and decreasing order of SEE. The range of correlation coefficient (0.62–0.76) for the equations in males is lower than that obtained for females (0.80 – 0.85). while the range of standard error of estimate in males (3.72 – 3.76) compares well with that obtained for females (3.80 – 3.87). The addition to and subtraction of SEE from the final estimate provides a range for TSH. As an illustration, a male individual with lateral condyle length of 60 mm will have a TSH of:

TSH = [(0.96 x 60) + 90.86] ± 4.36cm (see equation 1 Table 3.3)

= (57.6 + 90.86) ± 4.36cm = 148.46 ± 4.36cm

Table 3.1 Descriptive statistics for skeletal heigth and measurements of fragments of femur in indigenous South Africans

	Males			Females				
Measurements	N	Mean	Std Dev	N	Mean	Std Dev	F statistic	p-value
TSH	50	153.21	5.53	50	143.12	6.95	64.56	0.0000
MaxL	50	454.60	21.38	50	428.60	25.37	30.69	0.0000
BCB	50	78.72	4.05	50	69.96	5.04	91.79	0.0000
UEpL	50	95.32	5.96	50	85.74	6.59	58.16	0.0000
VND	50	32.31	2.44	50	28.20	2.52	68.65	0.0000
MCL	50	64.55	3.75	50	57.86	3.62	82.37	0.0000
LCL	50	64.73	3.58	50	59.86	4.41	36.75	0.0000
EpB	50	74.93	4.61	50	66.60	4.96	75.66	0.0000

TSH=Total skeletal height in cm
All femoral measurements are in mm:
MaxL= Maximum length of femur, BCB=Bicondylar breadth, UEpL=Upper epicondylar length, VND=Vertical neck diameter, MCL=Medial condyle length, LCL=Lateral condyle length, EpB=Epicondylar breadt

Table 3.2 Correlations of femoral measurements with stature and maximum length of femur in indigenous South Africans

	Males		Females	
Measurements	TSH	MaxL	TSH	MaxL
BCB	0.559	0.529	0.816	0.720
UEpL	0.608	0.653	0.785	0.799
VND	0.542	0.517	0.731	0.681
MCL	0.744	0.711	0.735	0.619
LCL	0.623	0.626	0.769	0.696
EpB	0.523	0.560	0.803	0.746

BCB=Bicondylar breadth, UEpL=Upper epicondylar length, VND=Vertical neck diameter, MCL=Medial condyle length, LCL=Lateral condyle length, EpB=Epicondylar breadth

Table 3.3 Equations for stature estimation (in cm), correlation and standard error of estimate from fragments of femur in indigenous South Africans

	Equations	Correlation	SEE	Accuracy (%)	
				1 SEE	2 SEE
	Male				
1	0.96(LCL) + 90.86	0.62	4.36	80.0	100.0
2	1.10(MCL) + 82.47	0.74	3.73	70.0	100.0
3	0.93(MCL) + 0.14(UEpL) + 79.42	0.75	3.72	100.0	100.0
4	1.24(MCL) - 0.17(BCB) + 86.22	0.75	3.75	100.0	100.0
5	1.02(MCL) + 0.19(UEpL) - 0.16(EpB) + 81.04	0.76	3.73	100.0	100.0
6	1.10(MCL) + 0.16(UEpL) - 0.21(BCB) + 83.78	0.76	3.73	90.0	100.0
	Female				
1	1.13(EpB) + 68.19	0.80	4.18	70.0	100.0
2	1.13(BCB) + 64.42	0.82	4.06	50.0	100.0
3	0.73(EpB) + 0.59(LCL) + 59.62	0.84	3.87	60.0	90.0
4	0.73(BCB) + 0.36(UEpL) + 61.08	0.84	3.88	60.0	100.0
5	0.55(EpB) + 0.53(LCL) + 0.53(VND) + 59.62	0.85	3.82	70.0	100.0

Fullys's soft tissue correction factors: TSH ≤ 153.5cm, add 10cm; between 153.6 and 165.4cm, add 10.5cm; and ≥ 165.5cm, add 11.5cm

For example, a male with MCL of dimemsion 70 mm will give TSH= (1.10 x 70) + 82.47= 77 + 82.47 = 159.47cm
Living stature will therefore be 159.47 + 10.5cm ± SEE = 169.97cm ± 3.73

Addition of a soft tissue factor of 10.0 cm for a skeletal height of less than or equal to153.5 cm as suggested by Fully (1956) gives a living stature estimate of:

ELS = 158.46 ± 4.36

Therefore, the estimated living stature of the individual will range between 154.10cm and 162.82cm.

Males showed moderate correlation between individual femoral variables and maximum length of femur while a higher degree of correlation was obtained in the female sample (Table 3.2). Regression equations that can be used in the estimation of maximum length of femur from various combinations of femoral variables are presented in Table 3.4. Equations derived for female samples presented with a higher correlation (0.80 – 0.83) compared with that obtained for the male sample (0.63 – 0.75). The standard error of estimate obtained for estimation of maximum length of femur from its fragments ranged from 1.46 to 1.69 cm for males and 1.48 to 1.54 cm in females.

The result of the accuracy of derived regression equations for estimation of maximum length of femur and TSH at 1 and 2 standard errors of estimate are shown in Tables 3.3 and 3.4. In general, a higher degree of accuracy was obtained in both sexes at 2 SEE.

Table 3.4 Equations for estimation of maximum length of femur (in mm), correlation and standard error of estimate from fragments of femur in indingenous South Africans

	Equations	Correlation	SEE	Accuracy (%)	
				1 SEE	2 SEE
	Male				
M1	0.37(LCL) + 21.23	0.63	1.69	90.0	100.0
M2	0.41(MCL) + 19.32	0.71	1.52	70.0	100.0
M3	0.47(MCL) - 0.10(BCB) + 20.88	0.72	1.53	70.0	100.0
M4	0.29(MCL) + 0.11(UEpL) + 17.04	0.74	1.47	70.0	100.0
M5	0.12(UEpL) + 0.36(MCL) - 0.10(BCB) + 19.14	0.75	1.46	70.0	100.0
M6	0.12(UEpL) - 0.10(BCB) + 0.37(MCL) - 0.01(LCL) + 19.21	0.75	1.48	70.0	100.0
	Female				
F1	0.31(UEpL) + 16.46	0.80	1.54	80.0	90.0
F2	0.24(UEpL) + 0.11(EpB) + 15.33	0.81	1.53	80.0	90.0
F3	0.24(UEpL) + 0.25(VND) + 15.03	0.82	1.48	80.0	100.0
F4	0.26(UEpL) - 0.06(MCL)+ 0.28(VND) + 16.14	0.82	1.49	80.0	100.0
F5	0.23(UEpL) - 0.17(MCL) + 0.28(VND) + 0.15(LCL) + 16.70	0.83	1.48	80.0	100.0
F6	0.04(EpB) + 0.15(LCL) + 0.26(VND) + 0.21(UEpL) - 0.19(MCL) + 16.63	0.83	1.50	80.0	100.0

3.5 DISCUSSION

In an attempt to derive equations for stature estimation using fragments of femur, Simmons *et al.* (1990) reported a difficulty in reproducing the measurements as suggested by Steele and McKern (1969). As a result Simmons *et al.* (1990) used eight standard measurements of the femur in the estimation of the stature of Americans. In the present study, four of the measurements were used because of the high coefficient of reproducibility that was obtained. These are: vertical diameter of femoral neck (VND), upper breadth of femur or upper epicondylar length (UEpL), bicondylar breadth (BCB), and epicondylar breadth (EpB). In addition to these, two other measurements, namely medial and lateral condylar lengths, were selected because they have been shown to be sexually dimorphic in indigenous South Africans by Asala *et al.* (2004) and also due to their high coefficient of reproducibility.

Each of these six measurements showed statistically significant sex differences. This indicates that fragments of the femur are sexually dimorphic in this population group which is in support of earlier observations made by Asala *et al.* (2004). A comparison of the mean measurements from the present study with those obtained by Asala *et al.* (2004) showed no statistically significant difference. The result of this comparison can be explained based on the fact that the two studies used recently acquired skeletal materials from the same population group. The two studies differ in that Asala *et al.* (2004) used a larger sample size and did not include the Tswana tribe.

All femoral measurements used in this study showed positive correlation with maximum length of the femur and stature (Table 3.2, page 70). Females consistently showed higher correlation coefficients compared to males. This is consistent with observations made from previous studies (Bidmos and Asala, 2005; Bidmos, 2006;

Chibba and Bidmos, 2007). Since femoral measurements are small in dimension compared to stature, one would expect that the degree of correlation is lower compared to that for the maximum length of the femur. However, most measurements of the femur showed a higher degree of correlation for stature compared with maximum length of femur in both sexes (Table 3.2, page 70). This observation is not unusual and has been reported in earlier studies by Simmons *et al.* (1990) and, Chibba and Bidmos (2007) using the femur and tibia respectively, in which higher correlation coefficients were obtained between measurements of these bones and stature compared to that between the maximum length of these bones and measurements of their fragments.

Measurements of the distal end of the femur consistently showed the best correlation with stature and maximum length of femur. In males, the medial and lateral condyle lengths showed the highest correlation with stature while the bicondylar breadth displayed the highest correlation in females (Table 3.2, page 70). However, the upper epicondylar length, one of the measurements on the proximal aspect of the femur, showed the highest correlation with maximum length of femur in females and also displayed the second best correlation in males (Table 3.2, page 70). The general trend in this study whereby measurements of the distal end of the femur displayed the highest correlation with stature and maximum length of femur differs from the observation made by Simmons *et al.* (1990). In the latter study, the upper epicondylar length, a proximal femora measurement consistently showed the best correlation with stature and maximum length of femur in both sexes.

Table 3.5 shows the correlation coefficients of comparable measurements of the femur in the present study and those of Simmons *et al.* (1990) with maximum length of the femur and stature. For three out of the four measurements, the

Table 3.5 Comparison of correlation coeffcients from Simmons*et al.* and present study

	Male				Female			
	Simmons *et al.*		Present study		Simmons *et al.*		Present study	
	MaxL	Stature	MaxL	Stature	MaxL	Stature	MaxL	Stature
UEpL (VHA)	0.592	0.564	0.653	0.608	0.513	0.432	0.799	0.785
VND	0.315	0.393	0.517	0.542	0.422	0.461	0.681	0.731
BCB	0.440	0.509	0.529	0.559	0.345	0.220	0.720	0.816
EpB (FDL)	0.465	0.560	0.560	0.523	0.415	0.329	0.746	0.803

correlation reported in this study was higher than that of Simmons *et al.* (1990) in males. However, all female measurements in this study showed a higher correlation compared with the corresponding measurements of Simmons *et al.* (1990). This indicates that the measured variables in this study have a higher predictive efficiency compared to those used by Simmons *et al.* (1990). The moderate to high correlations obtained in this study confirm the usefulness of fragments of femur of indigenous South African population group in the estimation of stature and maximum length of the femur. Regression equations derived from these measurements will therefore be of great assistance to forensic and physical anthropologists in South Africa in the estimation of stature.

3.6 CONCLUSIONS

Measurements of the proximal and distal ends of the femur of the indigenous South African population group have been shown to be sexually dimorphic in a previous study by Asala *et al.* (2004). In the present study, these measurements showed a moderate to high positive correlation with stature. The medial condyle length and bicondylar breadth, both being distal end measurements, showed the highest correlation in both males and females. The medial condyle length also showed the highest correlation with maximum length of femur in males while upper epicondylar length, a proximal measurement, displayed the best correlation in the female sample. Correlation coefficients for comparable measurements in this study are higher than those presented by Simmons *et al.* (1990) for African Americans, thereby showing a higher predictive efficiency of measurements used in this study. Regression equations for stature estimation and maximum length of femur using various combinations of measurements of the femur in both sexes are presented. The range of SEE for regression equations for estimation of stature in males and females is higher than that presented for intact femurs by Lundy and Feldesman (1987) and lower than that obtained for intact metatarsals (Byers *et al.*, 1989), metacarpals (Meadows and Jantz, 1992), calcanei (Bidmos and Asala, 2005; Bidmos, 2006) and fragmentary tibiae (Holland, 1992; Chibba and Bidmos, 2007). In the absence of intact femur, therefore, regression equations derived in this study are more reliable in the estimation of stature compared with the aforementioned skeletal elements i.e. metatarsals, metacarpals, calcanei and fragmentary tibiae.

3.7 Summary of chapter

Analysis of data collected from 100 complete skeletons of indigenous South Africans, equally distributed by sex, obtained from the Raymond A. Dart collection of human skeletons revealed that moderate to high correlation exits between fragments of femur and stature. By further subjecting the data to regression analysis, equations for the estimation of stature and maximum length of the femur were derived from six measurements of commonly preserved parts of the femur. Maximum length of femur can be predicted from these measurements. The standard error of estimate for the equations for stature estimation (3.72 – 4.38) was slightly higher than that presented for intact femur by Lundy and Feldesman (1987). The next chapter deals with assessment of the reliability of equations presented in this chapter on data collected from skeletons of South Africans of European Descent. Population specific equations for this population group will be derived.

Chapter Four

Fragments of Femur in the Estimation of Stature in South Africans of European Descent*

*Bidmos MA 2008 Stature reconstruction using fragmentary femora in South Africans of European descent. *Journal of Forensic Sciences*. 53 (5): 1044-1048…....……**Appendix 2**

4.1 Preamble

In the previous chapter, measurements of fragments of the femur of indigenous South Africans were shown to be useful in the estimation of maximum length of femur and stature. Sex specific regression equations were formulated for the studied population group. Since previous studies have shown that regression equations are population specific, this chapter tackles the issue of population specificity of these equations by assessing their reliability on samples of skeletons of South Africans of European Descent. In the event that this assumption is true, population specific equations will also be formulated for South Africans of European descent.

4.2 INTRODUCTION

There has been a lot of interest in the estimation of stature from different elements of the human skeleton since the 19th century when Pearson first derived regression equations for stature estimation (Krogman and İşcan, 1986). This method of stature estimation is based on the relationship between lengths of long bones and stature and is often referred to as the mathematical method (Lundy, 1985). The other method of stature estimation involves the use of the entire skeleton by summing up appropriate measurements from the skull to the foot (Lundy, 1985). This method was first suggested by Fully (1956) and is sometimes called the anatomical method. The advantages and disadvantages of these methods have been discussed in a previous study (Lundy, 1985).

Most studies conducted on stature estimation using the mathematical method revolve around the use of intact long bones of the upper and lower extremities (Trotter and Gleser, 1952, 1958; Lundy and Feldesman, 1987; De Medonca, 2000; Mall *et al.*, 2001; Radoinova *et al*, 2002; Dayal, 2002; Duyar and Pelin, 2003; Ozaslan *et al.*, 2003; Hauser *et al.*, 2005). Measurements of the skull (Chiba and Terazawa, 1998; Ryan and Bidmos, 2007) and postcranial elements (Meadows and Jantz, 1982; Byers et al., 1989; Holland, 1995; Ross and Konigsberg, 2002; Bidmos and Asala, 2005; Bidmos, 2006) have also been used in the formulation of regression equations for stature estimation. These equations are population and sex specific. The femur has been shown to be the most useful because it has the highest correlation with stature (Krogman and İşcan, 1986; Feldesman, 1992). Unfortunately, the femur is sometimes found in different states of fragmentation which therefore renders the equations derived from the intact bone inappropriate especially in forensic cases. This has necessitated the derivation of regression equations from fragments of the femur.

Steele and McKern (1969) conducted one of the earliest studies on stature estimation from fragments of long bones. They identified landmarks on the humerus, femur and tibia of Americans from which these bones were divided into segments. The percentage proportion of each segment to the maximum length of the long bone was then calculated. Stature was subsequently estimated from the calculated maximum length of the long bone using previously derived appropriate regression equation (Steele and McKern, 1969). Similar studies were carried out in India by Mysorekar *et al.* (1980, 1984). Simmons *et al.* (1990) suggested the use of standard measurements of the femur in the estimation of stature and maximum length of femur because of the difficulty in easily reproducing measurements of segments of the femur as suggested by Steele and McKern (1969).

Subsequently, standard tibial measurements were used for stature estimation in Americans (Holland, 1992), Guatemalans (Wright and Vásquez, 2003) and South Africans of European descent (Chibba and Bidmos, 2007) with different degrees of success. In the previous chapter, regression equations for stature estimation from fragments of the femur were presented for the indigenous South African population group. Since no previous study has been conducted on the usefulness of femoral measurements in stature estimation in South Africans of European descent, it is the aim of this study to (1) test the validity of regression equations derived in the previous chapter on a sample of skeletal remains of South Africans of European descent and (2) derive population and sex specific equations for estimation of stature and maximum length of the femur in this population group.

4.3 MATERIALS AND METHODS

4.3.1 Materials

4.3.1.1 Samples

The samples used in this study were obtained from the Raymond A. Dart Collection of Human Skeletons housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg, South Africa. Samples C (calibration sample) and D (independent sample) consisted of 100 and 20 complete skeletons respectively, equally distributed by sex. These skeletal remains represent an admixture of individuals who are descendants of migrants from Netherlands, United Kingdom, France, Germany, and other European countries (Steyn and İşcan, 1997).

4.3.1.2 Selection criteria

The following inclusion criteria were used in the selection of skeletons for this study: (a) presence of all skeletal elements that constitute stature, (b) documented ages at death which ranged between 29 – 75 years and (c) absence of pathologies and excessive osteophytic lipping. These skeletons belong to individuals that died between 1957 and 1998.

4.3.2 Methods

4.3.2.1 Description of measurements

Skeletons were selected using the simple random sampling technique. For each selected skeleton, total skeletal height (TSH) was estimated using the Fully's method (1956) as described in section 3.3.2 (pages 47-60). In addition, seven measurements as directed by Bräuer (1988) and as described in section 3.3.2.2 (pages 61-66) were taken on each left femur (Table 4.1).

Table 4.1 Definition of femoral measurements

Measurements	Abbreviation	Definition
Maximum length of femur	MaxL	the linear distance between the most superior part of the head of the femur and the mc inferior part of the medial condyle
Upper epicondylar length	UEpL	the linear measurement between the most superior point on the fovea capitis of the femur to tl inferior aspect of the greater trochanter
Vertical neck diameter	VND	the minimum linear distance between the superior and inferior points on the neck of the femur
Epicondylar breadth	EpB	the linear distance between the medial border of the medial condyle and the lateral border of tl lateral condyle
Bicondylar breadth	BCB	the linear distance between the medial and the lateral epicondyles of the femur
Medial condylar length	MCL	the linear distance between the most anterior and the most posterior points on the medial condyle
Lateral condylar length	LCL	the linear distance on the lateral condyle measured in an anteroposterior direction

All femoral measurements were taken using a vernier caliper except maximum length of femur and bicondylar breadth which were measured on an osteometric board.

4.3.2.2 Analysis of data

Statistical analyses were carried out on each group (male and female) separately using the 'Statistix' program. Means and standard deviations for TSH and all femoral measurements were obtained for each group. Each of the equations derived for estimation of skeletal height for ISA population group (Table 3.3, page 71) was used in the assessment of skeletal height of the independent sample D. Paired *t* test was used in assessing whether a statistically significant difference exists between the skeletal height using Fully's method (TSH_{Fully}) and estimated skeletal height using regression equation derived for ISA (TSH_{Est}). Analysis was carried out separately for males and females.

Thereafter, regression analyses were performed in stages on data collected from sample C. Firstly, TSH_{Fully} was regressed on individual and various combinations of measurements of the femur. Secondly, maximum length of femur (FML) was also regressed against each of the six femoral measurements.

4.4 RESULTS

4.4.1 Validity of regression equations for ISA on SAED

Regression equations derived in the previous chapter for ISA males overestimated skeletal height of SAED male skeletons in the independent sample D (Table 4.2). The differences were found to be statistically significant at $p \leq 0.05$. In the female group, differences between the compared parameters were not observed (Table 4.2). However, a bivariate scatter diagram of TSH_{Fully} against TSH_{Est} showed marked differences between the two parameters for cases at the upper limit of skeletal height (Figure 4.1). These cases were subsequently subjected to paired *t* test which showed the existence of significant differences between TSH_{Fully} and TSH_{Est}. These results therefore suggest population specificity of regression equations derived in the previous chapter and the need for the derivation of new equations for SAED.

4.4.2 Descriptive statistics

The results of the analysis of data collected for sample C showed mean ages of 58 and 62 years for males and females respectively. Males presented with statistically significant higher mean values compared to females with regard to total skeletal height (TSH_{Fully}) and all measurements of the femur (Table 4.3).

4.4.3 Regression analysis

The degree of association (correlation) between measurements of segments of the femur, maximum length of the femur (MAXL) and total skeletal height (TSH) are presented in Table 4.4. Generally, a moderate to strong correlation was observed.

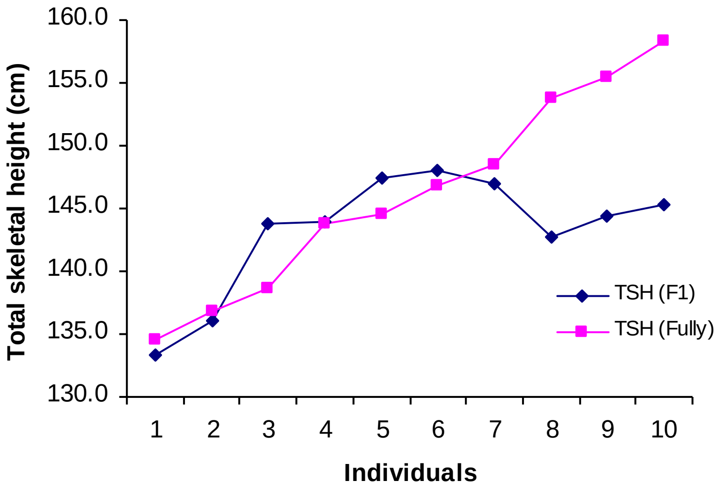
Table 4.2 Comparison between skeletal height from the Fully's method and estimated skeletal height using regression equations derived for ISA on samples of SAI

	Equations	SEE	$TSH_F - TSH_E$ Mean	$TSH_F - TSH_E$ p-value
	Male			
M1	0.96(LCL) + 90.86	4.36	4.290	**0.044**
M2	1.10(MCL) + 82.47	3.73	5.260	**0.018**
M3	0.93(MCL) + 0.14(UEpL) + 79.42	3.72	5.070	**0.016**
M4	1.24(MCL) - 0.17(BCB) + 86.22	3.75	6.580	**0.006**
M5	1.02(MCL) + 0.19(UEpL) - 0.16(EpB) + 81.04	3.73	5.050	**0.017**
M6	1.10(MCL) + 0.16(UEpL) - 0.21(BCB) + 83.78	3.73	5.150	**0.017**
	Female			
F1	1.13(EpB) + 68.19	4.18	2.900	0.185
F2	1.13(BCB) + 64.42	4.06	0.350	0.842
F3	0.73(EpB) + 0.59(LCL) + 59.62	3.87	2.660	0.169
F4	0.73(BCB) + 0.36(UEpL) + 61.08	3.88	-0.360	0.845
F5	0.55(EpB) + 0.53(LCL) + 0.53(VND) + 59.62	3.82	2.790	0.133

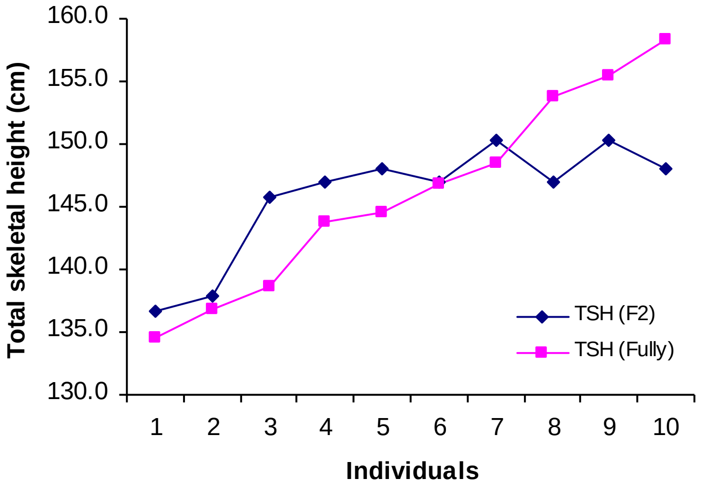
Figure 4.1 Comparisons between total skeletal height using Fully's method (on y-axis) on a test sample numbered 1 to 10 (x-axis) of South Africans of European Descent females (TSHFully) and estimated skeletal height using equations derived for indigenous South African females.

A. TSHF1: Estimated skeletal height using equation F1 in Table 3.3
B. TSHF2: Estimated skeletal height using equation F2 in Table 3.3
C. TSHF3: Estimated skeletal height using equation F3 in Table 3.3.
D. TSHF4: Estimated skeletal height using equation F4 in Table 3.3
E. TSHF5: Estimated skeletal height using equation F5 in Table 3.3

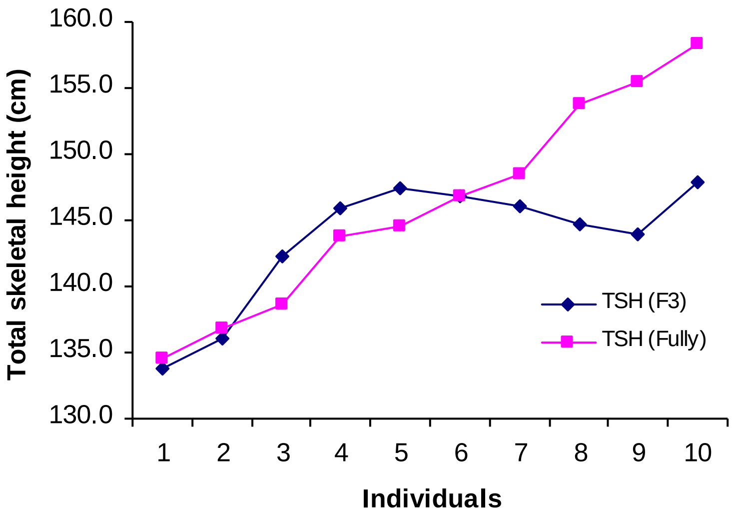
A


160.0
155.0
150.0
145.0
140.0
135.0
130.0
Total skeletal height (cm)
1
2
3
4
5
6
7
8
9
10
Individuals
TSH (F1)
TSH (Fully)

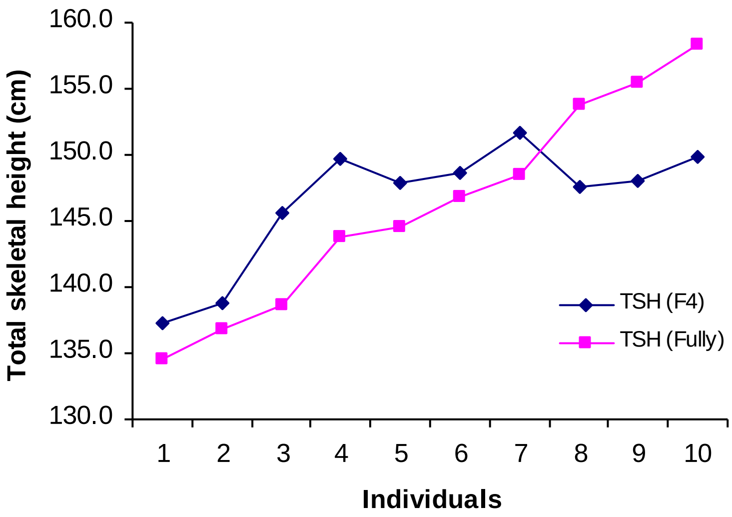
B


160.0
155.0
150.0
145.0
140.0
135.0
130.0
Total skeletal height (cm)
1
2
3
4
5
6
7
8
9
10
Individuals
TSH (F2)
TSH (Fully)

C


160.0
155.0
150.0
145.0
140.0
135.0
130.0
Total skeletal height (cm)
1
2
3
4
5
6
7
8
9
10
Individuals
TSH (F3)
TSH (Fully)

D


160.0
155.0
150.0
145.0
140.0
135.0
130.0
Total skeletal height (cm)
1 2 3 4 5 6 7 8 9 10
Individuals
TSH (F4)
TSH (Fully)

E

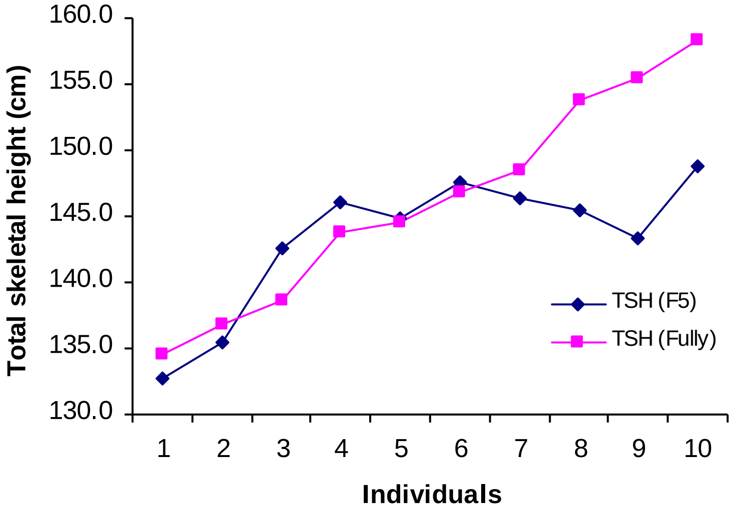

160.0
155.0
150.0
145.0
140.0
135.0
130.0
Total skeletal height (cm)
1 2 3 4 5 6 7 8 9 10
Individuals
TSH (F5)
TSH (Fully)

Table 4.3 Descriptive statistics for skeletal heigth and measurements of fragments of femur in South Africans of European Desce

	Males			Females				
Measurements	N	Mean	Std Dev	N	Mean	Std Dev	F statistic	p-value
TSH/cm	50	157.44	6.99	50	147.60	6.28	54.76	0.000
MaxL	50	465.22	27.56	50	433.80	22.18	39.43	0.000
BCB	50	80.68	4.18	50	72.22	3.91	109.22	0.000
UEpL	50	99.90	5.63	50	90.12	5.56	76.29	0.000
VND	49	33.99	2.70	50	29.92	2.77	54.76	0.000
MCL	50	65.33	3.70	50	59.54	3.19	70.32	0.000
LCL	50	65.18	3.53	50	60.30	3.47	48.61	0.000
EpB	48	75.99	3.35	44	67.37	4.11	122.21	0.000

TSH=Total skeletal height, MaxL= Maximum length of femur, BCB=Bicondylar breadth, UEpL=Upper epicondylar length, VND=Vertical neck diameter, MCL=Medial condyle length, LCL=Lateral condyle length, EpB=Epicondylar breadth

Table 4.4 Correlations of femoral measurements with stature and maximum length of femur in South Africans of European Descent

	Males		Females	
Variable	TSH	FML	TSH	FML
BCB	0.609	0.459	0.782	0.781
UEpL	0.661	0.610	0.562	0.623
VND	0.585	0.478	0.562	0.544
MCL	0.582	0.426	0.729	0.724
LCL	0.659	0.537	0.785	0.753
EpB	0.525	0.400	0.705	0.722

BCB=Bicondylar breadth, UEpL=Upper epicondylar length, VND=Vertical neck diameter
MCL=Medial condyle length, LCL=Lateral condyle length, EpB=Epicondylar breadth
FML= Femur Length, TSH= Total skeletal heigth

In males, all measured variables on the femur showed significant positive correlation with TSH. Upper epicondylar length (0.661) displayed the highest correlation with TSH for an individual measurement while epicondylar breadth (0.525) showed the lowest correlation (Table 4.4). A lower degree of correlation was obtained between maximum length of femur and femoral measurements. This ranged between 0.400 for epicondylar breadth and 0.610 for upper epicondylar length. In females, a strong positive correlation was observed between measurements of the femur and stature. Lateral condyle length (0.785) presented with the highest correlation while vertical neck diameter and upper epicondylar length (0.562) showed the least correlation. A similar pattern of correlation was obtained between maximum length of the femur and its measurements (Table 4.4).

Table 4.5 shows regression equations that can be used in the estimation of stature from femoral measurements. These equations are arranged in descending order of standard error of estimate and increasing order of correlation. Only the best equations with reasonable application are presented. In males, functions 1 and 2 were derived from the lateral condyle length and upper epicondylar length because they both showed the highest correlation for an individual measurement (Table 4.5). The other functions, formed from various combinations of measurements of the femur, presented with lower SEE (4.80 – 4.89) and higher correlation coefficient (0.73 – 0.75). Regression equations for females are also presented in Table 4.5. The highest correlation for an individual measurement was obtained for bicondylar breadth and lateral condylar length. The degree of correlation between TSH and different combinations of measurements ranged from 0.82 to 0.83. Equations for predicting TSH in females (Table 4.5) also presented with better accuracy as shown from the range of standard error of estimate (3.71- 3.95).

Table 4.5 Equations for stature estimation (in cm), correlation and standard error of estimate from fragments of femur in South Africans of European Descent

	Equations	Correlation	SEE
	Male		
M1	1.31(LCL) + 72.32	0.66	5.31
M2	0.82(UEpL) + 75.64	0.66	5.31
M3	0.50(UEpL) + 0.80(LCL) + 55.63	0.73	4.89
M4	0.53(UEpL) + 0.58(VND) + 0.58(LCL) - 0.22(EpB) + 63.68	0.74	4.81
M5	0.49(UEpL) + 0.54(VND) + 0.53(LCL) + 55.93	0.75	4.80
M6	0.55(UEpL) + 0.56(VND) + 0.41(LCL) + 0.41(BCB) - 0.49(EpB) + 61.07	0.75	4.80
	Female		
F1	1.26(BCB) + 56.96	0.78	3.95
F2	1.42(LCL) + 61.88	0.78	3.93
F3	1.21(LCL) + 0.38(EpB) + 48.83	0.82	3.78
F4	0.67(BCB) + 0.79(LCL) + 52.00	0.82	3.71
F5	0.37(BCB) + 1.03(LCL) + 0.17(EpB) + 47.07	0.83	3.78
F6	0.40(BCB) - 0.21(VND) + 1.07(LCL) + 0.23(EpB) + 45.43	0.83	3.81

In the estimation of maximum length of femur from measurements of its parts, regression equations for males showed moderate correlation between femoral measurements and maximum femur length (Table 4.6). In the female sample, moderate to high correlation were obtained. This ranged between 0.78 and 0.83 (Table 4.6). The standard error of estimate obtained for maximum femoral length estimation from its fragments ranged from 2.17 to 2.21 cm for males and 1.33 to 1.40 cm in females.

Table 4.6 Equations for estimation of maximum length of femur (in mm), correlation and standard error of estimate from fragments of femur in South Africans of European Descent

	Equations	Correlation	SEE
	Male		
M1	0.30(UEpL) + 16.73	0.61	2.21
M2	0.25(UEpL) + 0.21(VND) - 0.06(EpB) +18.31	0.62	2.17
M3	0.23(UEpL) - 0.04(BCB) + 0.22(VND) - 0.16(MCL) + 0.24(LCL) - 0.05(EpB) +17.81	0.64	2.21
M4	0.22(UEpL) + 0.16(VND) - 0.01(BCB) + 0.13(LCL) +12.61	0.65	2.20
M5	0.25(UEpL) + 0.21(VND) + 14.20	0.65	2.17
M6	0.22(UEpL) + 0.19(VND) + 0.02(BCB) + 0.24(LCL) - 0.19(MCL) + 12.73	0.66	2.19
	Female		
F1	0.44(BCB) + 11.42	0.78	1.40
F2	0.33(BCB) + 0.11(UEpL) + 9.95	0.80	1.36
F3	0.29(BCB) + 0.21(LCL) + 10.10	0.80	1.36
F4	0.22(BCB) + 0.09(UEpL) + 0.17(LCL) + 9.14	0.81	1.33
F5	0.26(BCB) + 0.11(UEpL) - 0.14(VND) + 0.18(LCL) + 7.81	0.82	1.33
F6	0.22(BCB) + 0.11(UEpL) - 0.14(VND) + 0.20(LCL) + 0.06(EpB) + 6.26	0.83	1.37

4.5 DISCUSSION

The results of the descriptive statistics showed that males presented with statistically significant higher mean value of total skeletal height than females (Table 4.3, page 92). It can therefore be inferred that males are generally taller than females which is in support of previous studies on stature estimation in South Africa (Lundy and Feldesman, 1987; Dayal, 2002, Ryan and Bidmos, 2007; Bidmos and Asala, 2005; Bidmos, 2006; Chibba and Bidmos, 2007). Males also showed higher mean values compared to females for all femoral measurements thereby confirming sexual dimorphism of femoral dimensions as reported in an earlier study by Steyn and İşcan (1997).

According to Steele and McKern (1969), Müller made the first attempt in estimating the maximum length of a long bone from measurements of its sections. Müller divided the humerus, radius and tibia into sections from which percentage contribution of each section to the maximum length of the long bone was obtained (1969). Steele and McKern (1969) criticised the exclusion of femur from Müller's selection since the femur is regarded as the singular bone with one of the highest correlation with stature. They replaced the radius with the femur in their study but used the method of delineating a long bone into sections as suggested by Müller.

In an attempt to derive equations for stature estimation using fragments of femur from a sample of a more recent skeletal collection, Simmons *et al.* (1990) reported a difficulty in reproducing the measurements as suggested by Steele and McKern (1969). As a result, Simmons *et al.* (1990) used eight standard measurements of the femur namely: (i) vertical diameter of femoral head, (ii) vertical diameter of femoral neck, (iii) upper breadth of femur, (iv) transverse diameter of midshaft, (v) bicondylar breadth, (vi) epicondylar breadth, (vii) lateral condylar height and (viii) medial condylar height, in the estimation of stature of Americans. Four of the above mentioned measurements were used in the present study because of the ease with which they could be reproduced. In addition to these, two other measurements namely medial and lateral condylar lengths were selected due to their high coefficient of reproducibility.

All measurements used in this study showed positive correlation with maximum length of the femur and stature (Tables 4.5 and 4.6, pages 95 and 97). Females consistently showed higher correlation coefficients compared to males which is in support of previous studies (e.g. Lundy and Feldesman, 1987; Dayal, 2002; Bidmos and Asala, 2005; Bidmos, 2006; Chibba and Bidmos, 2007). This could be due to less variability in females compared to males as shown in the value of standard deviation for total skeletal height and most femoral measurements. The range of correlation between femoral measurements and total skeletal height in males (0.66 – 0.75) is slightly lower than that obtained for the female sample (0.78 - 0.83). This result is expected as measurements of fragments of the femur are small in dimension as compared with total skeletal height. Therefore, the degree of correlation between these fragments and TSH in general should be moderate.

Measurements of the distal end of the femur consistently showed the best correlation with stature and maximum length of femur in females (Tables 4.5 and 4.6, pages 95 and 97). However, the upper epicondylar length, one of the measurements on the proximal aspect of the femur, showed the highest correlation with maximum length of femur and stature in males (Tables 4.5 and 4.6). The lateral condylar length showed the second highest correlation for stature and maximum length of femur in males. In general, measurements of the distal end of the femur displayed the highest correlation with stature and maximum length of femur in this study which is contrary to the observation made by Simmons *et al.* (1990). In the latter study (Simmons *et al.*, 1990), the upper epicondylar length, a proximal femora measurement consistently showed the best correlation with stature and maximum length of femur in both sexes.

The correlation coefficients of comparable measurements of femur in the present study and those of Simmons *et al*. (1990) with maximum length of femur and stature are presented in Table 4.7. The general trend reveals that measurements in this study showed a higher correlation compared with corresponding measurements of Simmons *et al.* (1990) in both sexes indicating that measurements in this study have a higher predictive efficiency compared to those used by Simmons *et al.* (1990). The moderate to high degree of correlations obtained in the present study confirms the usefulness of fragments of femur in the estimation of stature in South Africans of European descent. Practitioners of forensic anthropology in South Africa will therefore find the regression equations presented in this study useful when intact long bones are not present for analysis.

The accuracy of each regression equation derived in this study was assessed using the obtained standard error of estimate (SEE). Regression equations for stature estimation in males presented with slightly higher SEE compared to those obtained for females (Table 4.5, page 95). Similar results were obtained for range of SEE for regression equations for estimation of maximum length of femur from its fragments (Table 4.6, page 97). While this is in support of previous observation made by Chibba and Bidmos (2007), it contradicts that made by Simmons *et al.* (1990) whereby similar range of SEE were obtained for both sexes.

Table 4.8 shows a comparison of the range of SEE from some selected previous studies with that from the present study. The range of SEE from the present study is lower than that obtained for intact calcanei, metatarsals, metacarpals and fragmentary tibiae. This suggests that regression equations derived from the present study using

Table 4.7 Comparison of correlation coeffcients from Simmons et al. and present study

	Male				Female			
	Simmons *et al.*		Present study		Simmons *et al.*		Present study	
	MaxL	Stature	MaxL	Stature	MaxL	Stature	MaxL	Stature
UEpL (VHA)	0.606	0.587	0.610	0.661	0.632	0.526	0.623	0.562
VND	0.384	0.312	0.478	0.585	0.409	0.409	0.544	0.562
BCB	0.541	0.512	0.459	0.609	0.445	0.294	0.781	0.782
EpB (FDL)	0.521	0.493	0.400	0.525	0.537	0.428	0.722	0.705

Table 4.8 Comparison of standard errors of estimate for stature by different authors

Investigator	Skeletal elements	SEE
Lundy and Feldesman (1987)	Long bones of upper and lower limbs	1.8-5.3
Dayal (2003)	Long bones of upper and lower limbs	1.8-5.5
Trotter and Gleser (1952a)	Long bones of upper and lower limbs	3.0-5.1
Bidmos and Asala (2005)	Calcaneus	4.0-5.9
Holland (1995)	Calcaneus	4.1-6.3
Bidmos (2006)	Calcaneus	4.2-5.4
Byers *et al.* (1989)	Metatarsals	4.0-7.6
Meadows and Jantz (1992)	Metacarpals	5.1-5.7
Chibba and Bidmos (2007)	Fragments of tibia	5.2-6.7
Simmons *et al*. (1990)	Fragments of femur	5.5-7.2

fragments of femur are more accurate in the estimation of stature compared to those derived in earlier studies using the calcaneus, metatarsals, metacarpals and fragments of long bones of the lower extremity.

4.6 CONCLUSION

Regression equations were derived for estimation of stature and maximum length of femur from measurements of fragments of the femur. Females showed higher correlation between measured variables and both stature and maximum length of femur compared to males. This allowed for formulation of more accurate regression equations for females compared to males. The accuracy of the equations in this study is lower than that obtained for intact long bones but higher than that for other skeletal elements like metatarsals, metacarpals, intact calcaneus and fragments of tibia. Therefore, intact long bones should be used in the estimation of stature when they are available for forensic analysis. However, in the absence of intact long bones, equations presented in this study can offer a reasonable estimate of stature.

4.7 Summary of chapter

In the previous chapter, regression equations for stature estimation from fragments of the femur were presented for the indigenous South African population group. An assessment of the reliability of these equations on data collected from the current study confirmed population and sex specificity of regression equations presented in the previous chapter. New regression equations are subsequently formulated in the current chapter. The range of standard error of estimate for these equations (3.71 - 5.31) is slightly higher than those obtained from previous chapter (3.72 – 4.38). Also these equations are less accurate in the estimation of stature compared with those derived by Dayal *et al*. (2008b) for intact long bones (2.13 - 3.79). It is therefore suggested that in the absence of intact femur, regression equations derived from the present study can provide a reliable estimate of adult stature.

Chapter Five

Evaluation of the Accuracy of the Direct and Indirect Methods of Stature Estimation*

* Bidmos MA 2009 Fragmentary Femora: Evaluation of the accuracy of the direct and indirect methods in stature reconstruction. *Forensic Science International*… **In Press (Appendix 3)**

5.1 Preamble

Selected measurements of fragments of the femur have been used in the derivation of regression equations for stature estimation in Americans (Steele and McKern, 1969; Steele, 1970; Simmons *et al.*,1990). In the previous two chapters, population specific regression equations were formulated for the direct estimation of stature from measurements of fragments of the femur. The alternative method is to estimate stature indirectly by the initial estimation of maximum length of femur and subsequent estimation of stature using an appropriate regression equation. By using a hypothetical case as an illustration, Steele (1970) concluded that the indirect method provides a more accurate estimate of stature compared to the direct method. In this chapter, the issue of the accuracy of the two methods will be investigated using a reasonably large sample size.

5.2 INTRODUCTION

Steele and McKern (1969) conducted one of the earliest studies on stature reconstruction from fragments of long bones. They identified landmarks on the humerus, femur and tibia of pre-historic Americans and thereafter divided these bones into segments based on the identified landmarks. The percentage proportion of each segment to the maximum length of the long bone was then calculated. Regression equations were also presented for the estimation of stature and maximum length of these bones. In 1970, Steele conducted a similar study using the same technique and skeletal elements (i.e. humerus, femur and tibia). However, his sample consisted of modern American population with groups of European and African descent obtained from the Terry Collection housed in the Smithsonian National Museum of Natural History. He derived regression formulae for the estimation of maximum length of these bones from measurements of their segments (Steele, 1970). An estimate of the living stature can be obtained by using a two step approach. The initial step involves the estimation of maximum length of the specific long bone from measurements of its fragments. Thereafter, the estimated maximum length of the long bone can be substituted into the appropriate equation of Trotter and Gleser (1958). This is referred to as the indirect method of stature estimation from fragments of long bones.

The direct method allows for the estimation of stature directly from individual or combinations of measurements of fragments of long bones. Steele (1970) presented such equations and attempted to compare the accuracy of the two methods. He concluded that the indirect approach should yield a more accurate estimate of stature but failed to give any detailed account of how he arrived at the conclusion. In 1990, Simmons and co-workers revised Steele's method (1970) by suggesting the use of standard measurements of the femur. While they (1990) presented regression equations for the estimation of maximum length of the femur and stature from three of the eight studied variables, they made no attempt to discuss the issue of the accuracy of the indirect method over the direct method as suggested by Steele (1970). Subsequent studies as documented in the previous two chapters on stature reconstruction from fragmentary femora in indigenous South Africans (chapter 3) and South Africans of European descent (chapter 4) did not address this issue. It is therefore the aim of this study to investigate the accuracy of these two methods of stature reconstruction from measurements of fragments of the femur.

5.3 MATERIALS AND METHODS

5.3.1 Materials

The samples used in this study were obtained from the Raymond A. Dart Collection of Human Skeletons housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg, South Africa. The sample consisted of 120 complete skeletons of South Africans equally distributed by sex and population group.

5.3.2 Methods

5.3.2.1 Measurements

Skeletons were selected using the simple random sampling technique. For each selected skeleton, total skeletal height (TSH_{Fully}) was estimated using the Fully's method (1956). Seven measurements as described by Bräuer (1988) were taken on each left femur. These are:

1. maximum length of femur (MaxL),
2. upper epicondylar length or upper breadth (UpBr),
3. vertical neck diameter (VND),
4. epicondylar breadth (EpB or FDL),
5. bicondylar breadth (BCB),
6. medial condyle length (MCL) and
7. lateral condyle length (LCL).

Definitions of these measurements and procedure for calculating total skeletal height are detailed in chapter 3 (see section 3.3.2, pages 47-60). All femoral measurements were taken using a vernier caliper except maximum length of the femur and bicondylar breadth which were measured on an osteometric board.

5.3.2.2 Analysis of data

Statistical analyses were carried out on each of the four groups separately using the 'Statistix' program. Means and standard deviations for skeletal height using Fully's method (TSH_{Fully}) and all femoral measurements were obtained for each group. Since regression equations for estimation of skeletal height using maximum length of the femur were not presented in previous studies on South Africans (Lundy and Feldesman, 1989; Dayal *et al.* 2008b) such equations were derived in the current study. This became necessary as previous studies on stature reconstruction from fragments of long bones (Steele and McKern, 1969; Steele, 1970; Simmons *et al*., 1990) utilized the maximum length and not the bicondylar length of the femur. This will also allow for reasonable comparisons to be made between previous studies by these authors and the current study.

In assessing the accuracy of the direct method, the obtained dimensions from the current study were substituted into each of the previously derived equations for ISA (Table 3.3, page 71) and SAED (Table 4.5, page 95) in order to obtain an estimate of the skeletal height (TSH_{Est}). Analyses were carried out separately for each group. An assessment of the differences between the estimated skeletal height (TSH_{Est}) and the obtained skeletal height using the Fully's method (TSH_{Fully}) was performed using the paired *t* test. Mean of the differences, p-value and correlation between TSH_{Fully} and TSH_{Est} were calculated.

The indirect method consisted of two steps. Step one involved the calculation of the maximum length of the femur using the appropriate equations previously derived for ISA (Table 3.4, page 73) and SAED (Table 4.6, page 97). Thereafter, TSH_{Est} was calculated by substituting the obtained maximum length into appropriate regression equations derived in this study. The mean of the difference between the calculated TSH_{Est} and TSH_{Fully} was thereafter calculated. The paired *t* test was used to assess whether statistically significant differences exist between these two parameters. The correlation between them was also calculated for each equation.

5.4 RESULTS

5.4.1 Descriptive statistics

Descriptive statistics for each of the four groups are presented in Table 5.1. SAED males presented with the highest values for all measurements followed by ISA males. The smallest measurements were displayed by the ISA female group.

5.4.2 Regression analysis

Due to the notable differences in the dimensions of the measured variables and in consonance with the advice of previous anthropologists concerning population and sex specificity of regression equations (Trotter and Gleser, 1952a, 1952b; Musgrave and Harneja, 1978; Radoinova *et al*., 2002; Petrovečki *et al*., 2007), new regression equations for the estimation of skeletal height from maximum length of the femur were derived (Table 5.2). A significantly strong positive correlation was shown between maximum length of femur and skeletal height (TSH_{Fully}) for all groups. The ISA female group presented with the best correlation (0.932) while their male counterparts presented with the least correlation (0.832). The range of the obtained standard error of estimate for these equations (2.55 for ISA female to 3.06 for ISA males) is also low; indicating a high accuracy of the presented regression equations.

5.4.3 Comparison of accuracy of direct and indirect methods

Table 5.3 shows the mean of the difference between obtained skeletal heights using Fully's method (TSH_{Fully}) and the estimated skeletal height from appropriate regression equations (derived for the direct estimation of skeletal height) of ISA and SAED. The mean difference between TSH_{Fully} and TSH_{Est} for all equations (except equation 7) is minimal and statistically insignificant ($p \leq 0.05$). The overestimation of

Table 5.1 Descriptive statistics

	ISA Males			ISA Females			SAED Males			SAED Females		
Measurements	N	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std Dev	N	Mean	Std De
TSH_F	30	153.38	5.03	30	140.38	5.93	30	157.50	6.46	30	146.13	6.31
MaxL	30	460.60	19.70	30	419.27	21.61	30	466.10	24.04	30	427.67	22.9
BCB	30	79.70	4.06	30	68.17	4.86	30	81.43	4.64	30	71.80	3.35
UEpL	30	95.37	4.89	30	84.45	6.03	30	99.58	6.09	30	89.89	4.78
VND	30	33.31	2.11	30	27.18	2.41	30	34.54	2.53	30	29.37	2.42
MCL	30	65.10	3.25	30	56.53	3.86	30	64.42	4.44	30	59.45	2.68
LCL	30	65.40	3.57	30	58.20	4.21	30	65.07	3.98	30	59.81	2.87
EpB	30	75.79	4.10	30	65.18	4.67	30	76.13	4.28	30	66.26	3.03

TSH_F =Total skeletal height using Fully's method (

All femoral measurements are in mm:

MaxL= Maximum length of femur, BCB=Bicondylar breadth, UEpL=Upper epicondylar length, VND=Vertical neck diameter, MCL=Medial condyle length, LCL=Lateral condyle length, EpB=Epicondylar breadth

Table 5.2 Regression equations for estimation of skeletal heigth from maximum length of femur

Equations	SEE	R
ISA Male		
0.22(MaxL) + 55.50	3.06	0.832
ISA Female		
0.26(MaxL) + 33.74	2.55	0.932
SAED Male		
0.232(MaxL) + 49.44	2.85	0.915
SAED Female		
0.257(MaxL) + 36.07	2.66	0.906

Table 5.3 Comparison between skeletal height using Fully's method and estimated skeletal height using regression equations for the direct method

	Equations	SEE	$TSH_F - TSH_E$ Mean	p-value	R
	ISA Male				
1	0.96(LCL) + 90.86	4.36	-0.260	0.732	0.58
2	1.10(MCL) + 82.47	3.73	-0.710	0.276	0.72
3	0.93(MCL) + 0.14(UEpL) + 79.42	3.72	0.073	0.911	0.71
4	1.24(MCL) - 0.17(BCB) + 86.22	3.75	-0.013	0.984	0.70
5	1.02(MCL) + 0.19(UEpL) - 0.16(EpB) + 81.04	3.73	-0.050	0.938	0.72
6	1.10(MCL) + 0.16(UEpL) - 0.21(BCB) + 83.78	3.73	-0.527	0.432	0.69
	ISA Female				
7	1.13(EpB) + 68.19	4.18	-1.460	**0.043**	0.77
8	1.13(BCB) + 64.42	4.06	-1.063	0.157	0.76
9	0.73(EpB) + 0.59(LCL) + 59.62	3.87	-1.163	0.114	0.77
10	0.73(BCB) + 0.36(UEpL) + 61.08	3.88	-0.857	0.221	0.79
11	0.55(EpB) + 0.53(LCL) + 0.53(VND) + 59.62	3.82	-0.343	0.627	0.78
	SAED Male				
12	1.31(LCL) + 72.32	5.31	-0.067	0.941	0.67
13	0.82(UEpL) + 75.64	5.31	0.210	0.810	0.69
14	0.50(UEpL) + 0.80(LCL) + 55.63	4.89	0.010	0.991	0.72
15	0.53(UEpL) + 0.58(VND) + 0.58(LCL) - 0.22(EpB) + 63.68	4.81	0.020	0.981	0.74
16	0.49(UEpL) + 0.54(VND) + 0.53(LCL) + 55.93	4.80	-0.363	0.661	0.74
17	0.55(UEpL) + 0.56(VND) + 0.41(LCL) + 0.41(BCB) - 0.49(EpB) + 61.07	4.80	-0.460	0.574	0.75
	SAED Female				
18	1.26(BCB) + 56.96	3.95	-1.287	0.136	0.69
19	1.42(LCL) + 61.88	3.93	-0.667	0.411	0.72
20	1.21(LCL) + 0.38(EpB) + 48.83	3.78	-0.243	0.755	0.74
21	0.67(BCB) + 0.79(LCL) + 52.00	3.71	-1.223	0.116	0.77
22	0.37(BCB) + 1.03(LCL) + 0.17(EpB) + 47.07	3.78	-0.353	0.643	0.76
23	0.40(BCB) - 0.21(VND) + 1.07(LCL) + 0.23(EpB) + 45.43	3.81	-1.070	0.172	0.75

TSH_{Fully} by these equations is as low as 0.01 cm (equation 4, ISA male group; equation 14, SAED male) while the highest difference (1.3 cm) was observed for equation 18 in the SAED female population group. Equation 3 (for ISA male) underestimated TSH_{Fully} by 0.1 cm and again this difference is not statistically significant. Of the 23 equations derived for direct estimation of skeletal height, only one (equation 7) showed a statistically significant difference between the compared skeletal heights. This equation overestimated TSH_{Fully} by 1.4 cm.

There is a general overestimation of TSH_{Fully} using the indirect method of stature estimation. The difference between TSH_{Fully} and TSH_{Est} in the ISA male group is statistically significant for all equations and ranged from 1.6 cm (equation 1, Table 5.4) to 3.7 cm (equation 4, Table 5.4). Three (equations 7, 8 and 11; Table 5.4) of the six equations in the ISA female group produced statistically significant overestimation of $TSH_{Fully.}$ A similar observation compared to the ISA female was made in the SAED female group whereby three (equations 20, 21 and 24; Table 5.4) equations also produced significant overestimation of TSH_{Fully}. However, only one equation for SAED males (equation 16, Table 5.4) showed significant difference between the skeletal heights in comparison.

A general trend of moderate to strong positive correlation was shown for all groups for both direct and indirect methods. In the direct estimation of skeletal height, the least correlation (0.58) was shown by equation 1 (Table 5.3) while equation 10 (Table 5.3) showed the highest correlation (0.79). A similar result was obtained for correlation between skeletal heights for equations derived for the indirect estimation of skeletal height. This ranged between 0.58 for equation 1 (Table 5.4) and 0.79 for equation 12 (Table 5.4).

Table 5.4 Comparison between skeletal height using Fully's method and estimated skeletal height using regression equations for the indirect method

	Equations	SEE	$TSH_F - TSH_E$ Mean	$TSH_F - TSH_E$ p-value	R
	ISA Male				
1	0.37(LCL) + 21.23	1.69	-1.563	**0.045**	0.58
2	0.41(MCL) + 19.32	1.52	-2.840	**0.000**	0.72
3	0.47(MCL) - 0.10(BCB) +20.88	1.53	2.156	**0.000**	0.69
4	0.29(MCL) + 0.11(UEpL) + 17.04	1.47	-3.717	**0.000**	0.69
5	0.12(UEpL) + 0.36(MCL) - 0.10(BCB) + 19.14	1.46	-2.930	**0.000**	0.66
6	0.12(UEpL) - 0.10(BCB) + 0.37(MCL) - 0.01(LCL) + 19.21	1.48	-3.077	**0.000**	0.66
	ISA Female				
7	0.31(UEpL) + 16.46	1.54	-2.073	**0.010**	0.72
8	0.23(UEpL) - 0.17(MCL) + 0.28(VND) + 0.15(LCL) + 16.70	1.48	-2.413	**0.002**	0.77
9	0.24(UEpL) + 0.11(EpB) + 15.33	1.53	-0.700	0.314	0.78
10	0.26(UEpL) - 0.06(MCL)+ 0.28(VND) + 16.14	1.49	-1.267	0.077	0.77
11	0.24(UEpL) + 0.25(VND) + 15.03	1.48	-2.633	**0.001**	0.78
12	0.04(EpB) + 0.15(LCL) + 0.26(VND) + 0.21(UEpL) - 0.19(MCL) + 16.63	1.50	-0.537	0.430	0.79
	SAED Male				
13	0.30(UEpL) + 16.73	2.21	-0.060	0.945	0.68
14	0.25(UEpL) + 0.21(VND) - 0.06(EpB) +18.31	2.17	1.593	0.066	0.71
15	0.23(UEpL) - 0.04(BCB) + 0.22(VND) - 0.16(MCL) + 0.24(LCL) - 0.05(EpB) +17.81	2.21	0.053	0.950	0.69
16	0.22(UEpL) + 0.16(VND) - 0.01(BCB) + 0.13(LCL) +12.61	2.20	-2.573	**0.003**	0.73
17	0.25(UEpL) + 0.21(VND) + 14.20	2.17	0.527	0.522	0.73
18	0.22(UEpL) + 0.19(VND) + 0.02(BCB) + 0.24(LCL) - 0.19(MCL) + 12.73	2.19	0.867	0.302	0.72
	SAED Female				
19	0.44(BCB) + 11.42	1.40	-0.467	0.587	0.69
20	0.33(BCB) + 0.11(UEpL) + 9.95	1.36	-1.790	**0.043**	0.69
21	0.29(BCB) + 0.21(LCL) + 10.10	1.36	-1.677	**0.041**	0.76
22	0.22(BCB) + 0.09(UEpL) + 0.17(LCL) + 9.14	1.33	-0.927	0.255	0.74
23	0.26(BCB) + 0.11(UEpL) - 0.14(VND) + 0.18(LCL) + 7.81	1.33	-0.490	0.551	0.72
24	0.22(BCB) + 0.11(UEpL) - 0.14(VND) + 0.20(LCL) + 0.06(EpB) + 6.26	1.37	-2.417	**0.006**	0.72

5.5 DISCUSSION

The estimation of stature from fragments of long bones (e.g. the femur) can be carried out by using direct or indirect methods. The former involves the direct estimation of stature from measurements of fragments of the femur while the latter consists of two steps, an initial estimation of the maximum length of the femur which is followed by the estimation of stature from the estimated maximum length. Steele (1970) observed that the two methods yielded different stature estimates in a hypothetical case he used as an illustration. He noted that "…the differences in stature estimates by the two methods to be greatest in White males, least in White females, and intermediate in Negro females and Negro males, in that order" (Steele, 1970: page 91). He argued that the lack of agreement of the estimates from the two different methods could be explained based on sample differences and ultimately the effect of a positive secular trend on stature in Americans (Steele, 1970). On the issue of differences in sample size, it is worth mentioning here as already explained in the introduction above that the indirect method is a two step approach which involves the initial estimation of maximum length of the long bone and subsequent calculation of stature from the estimated maximum length of the long bone.

In the hypothetical case described by Steele (1970), the maximum length of femur was estimated using one of the regression equations he derived from a sample of skeletons obtained from the Terry Collection. However, the equation he used in the estimation of stature from the maximum length of the femur was formulated by Trotter and Gleser (1958) using a sample of long bones that were obtained from skeletal remains of military personnel of the Korean War. The limitation regarding sample differences in Steele's (1970) study was overcome in the current study. The samples used in the derivation of equations for maximum length of femur as well as those used in the formulation of equations for the estimation of skeletal height were all obtained from the Raymond A. Dart Collection. In addition, the samples are quite similar in terms of dimensions and as such are not constrained by the issue of secular trend.

Steele (1970) favoured the use of the indirect method even though it is more complicated compared to the direct method since it involves a two-step approach. In contrast to what Steele (1970) observed, results of the analyses from the current study showed that the direct method provides a more accurate estimate of skeletal height compared to the indirect method. With the exception of one equation (equation 7, Table 5.3), estimates of skeletal height from all equations derived for the direct estimation of skeletal height (TSH_{Est}) from measurements of fragments of the femur showed strong positive correlation with skeletal height using Fully's method (TSH_{Fully}). Also, the differences between these two skeletal heights were not only minimal and inconsequential in most cases but also statistically insignificant. These indicate that there is a strong agreement between TSH_{Fully} and TSH_{Est}. However, most of the equations used in the indirect estimation of skeletal height yielded statistically significant differences between TSH_{Fully} and TSH_{Est}. Therefore, it could be inferred that equations used in the direct estimation of skeletal height are more accurate compared to those formulated for the indirect method.

The magnitude of the value of the standard error of estimate is another important factor worthy of consideration as it is considered to be a measure of accuracy of a regression equation. According to Trotter and Gleser (1958), Keen in 1953 defined the standard error of estimate as "a measure of expected accuracy of a stature estimate of an individual who belongs to the same population from which the equation was derived". A high standard error of estimate indicates a low accuracy and vice versa. A causal look at the range of SEE for regression equations for the direct (3.71 – 5.31) and indirect method

(1.33 – 2.21), as shown in Tables 5.3 and 5.4 respectively, may lead to the erroneous conclusion that the indirect method is the more accurate of the two methods.

However, if one considers the fact that the second step in the estimation of stature from the estimated maximum length of femur requires that the SEE (from the first step as shown in Table 5.4) should be adjusted, it is expected that the final calculated SEE for the indirect method will be higher than that of the direct method. Steele (1970: page 90) instructed that “the second step is to adjust the standard error to take into account the fact that the femur length also has a standard error…adjustment is made by multiplying the standard error of the estimated femur length by the first constant in the stature regression formula, and then adding the product to the standard error of the estimated stature”. Table 5.5 shows the SEE for each of the equation in Table 5.4 after the necessary adjustment using the coefficient and constant from the appropriate equation presented in Table 5.2. The magnitude of these adjusted SEE (range = 6.08 – 7.98), expectedly, is higher than that obtained for the direct method (Table 5.3) which is a further confirmation of the accuracy of the latter method.

Table 5.5 Adjusted SEE for regression equations for indirect method

	Equations	SEE	Adjusted SEE
	ISA Male		
1	0.37(LCL) + 21.23	1.69	6.78
2	0.41(MCL) + 19.32	1.52	6.40
3	0.47(MCL) - 0.01(BCB) +20.88	1.53	6.43
4	0.29(MCL) + 0.11(UEpL) + 17.04	1.47	6.29
5	0.12(UEpL) + 0.36(MCL) - 0.10(BCB) + 19.14	1.46	6.27
6	0.12(UEpL) - 0.10(BCB) + 0.37(MCL) - 0.01(LCL) + 19.21	1.48	6.32
	ISA Female		
7	0.31(UEpL) + 16.46	1.54	6.55
8	0.23(UEpL) - 0.17(MCL) + 0.28(VND) + 0.15(LCL) + 16.70	1.48	6.40
9	0.24(UEpL) + 0.11(EpB) + 15.33	1.53	6.53
10	0.26(UEpL) - 0.06(MCL)+ 0.28(VND) + 16.14	1.49	6.42
11	0.24(UEpL) + 0.25(VND) + 15.03	1.48	6.40
12	0.04(EpB) + 0.15(LCL) + 0.26(VND) + 0.21(UEpL) - 0.19(MCL) + 16.63	1.50	6.45
	SAED Male		
13	0.30(UEpL) + 16.73	2.21	7.98
14	0.25(UEpL) + 0.21(VND) - 0.06(EpB) +18.31	2.17	7.88
15	0.23(UEpL) - 0.04(BCB) + 0.22(VND) - 0.16(MCL) + 0.24(LCL) - 0.05(EpB) +17.81	2.21	7.98
16	0.22(UEpL) + 0.16(VND) - 0.01(BCB) + 0.13(LCL) +12.61	2.20	7.95
17	0.25(UEpL) + 0.21(VND) + 14.20	2.17	7.88
18	0.22(UEpL) + 0.19(VND) + 0.02(BCB) + 0.24(LCL) - 0.19(MCL) + 12.73	2.19	7.93
	SAED Female		
19	0.44(BCB) + 11.42	1.40	6.26
20	0.33(BCB) + 0.11(UEpL) + 9.95	1.36	6.16
21	0.29(BCB) + 0.21(LCL) + 10.10	1.36	6.16
22	0.22(BCB) + 0.09(UEpL) + 0.17(LCL) + 9.14	1.33	6.08
23	0.26(BCB) + 0.11(UEpL) - 0.14(VND) + 0.18(LCL) + 7.81	1.33	6.08
24	0.22(BCB) + 0.11(UEpL) - 0.14(VND) + 0.20(LCL) + 0.06(EpB) + 6.26	1.37	6.18

5.6 CONCLUSION

In the absence of intact long bones, stature reconstruction from measurements of fragments of long bones is essential in the identification process as it complements other demographic information such as sex, age and population affinity. It has been suggested that the indirect method of stature estimation which involves the initial estimation of maximum length of the femur and subsequent estimation of stature from the estimated femur length gives a more accurate result. This is contrary to the results of the present study in which the direct method has been shown to be more accurate and is less complicated compared to the indirect method. This study therefore recommends the use of the direct method in situations where such formulae exist; however, in the absence of regression formulae for the direct estimation of stature for fragments of long bones, the indirect method can also yield a reasonable degree of accuracy.

5.7 Summary of chapter

The current study utilized 120 complete skeletons in the assessment of the accuracy of the direct and indirect methods of stature estimation from fragments of the femur. Total skeletal height for each of the skeletons (TSH_{Fully}) was calculated using the Fully's method. Measurements of fragments of the femur acquired from the current study were substituted into each of the previously derived equations for Indigenous South Africans (ISA) and South Africans of European Descent (SAED) in order to obtain an estimate of the skeletal height (TSH_{Est}). Analyses were carried out separately for each group. An assessment of the differences between the estimated skeletal height (TSH_{Est}) and the obtained skeletal height using the Fully's method (TSH_{Fully}) using the paired *t* test revealed no significant difference for all equations (except one) in the direct estimation of skeletal height. However, a number of indirect equations significantly overestimated TSH_{Fully}. These observations indicate that the direct method is more accurate than the indirect method. Since it is also less complicated, it is therefore the preferred of the two methods contrary to earlier recommendation made by Steele (1970).

Chapter Six

Metatarsals in the Estimation of Stature*

* Bidmos MA 2008 Metatarsals in the estimation of stature in South Africans. *Journal of Legal and Forensic Medicine.* 15: 505-9……………………………………………..…….**Appendix 4**

6.1 Preamble

It is well established that the intact femur shows the best correlation with stature. It has also been shown in chapters 3 and 4 that fragments of the femur can provide reasonable estimate of stature in South Africans. In the previous chapter, it was shown that equations derived for the direct estimation of stature from fragments of the femur provide more accurate results compared to the indirect method. It was suggested that the direct method should be used as it is less complicated compared to the indirect method. Just like the femur, metatarsals are also classified as long bones and are sometimes available for analysis in forensic cases. However, unlike the femur, its forensic application especially in South Africa has never been investigated. How will its measurements compare to those of fragments of the femur in the estimation of stature? This chapter investigates the potential of metatarsals, one of the least used bones in forensic anthropology in South Africa, in stature reconstruction.

6.2 INTRODUCTION

Recent trends in forensic anthropology have shown an increased interest in forensic age diagnosis using regression analysis (Schmeling *et al.*, 2006a; Cameriere *et al.*, 2006a; Cameriere *et al.*, 2006b; Braga and Tril, 2007). According to Krogman and İşcan (1986), this statistical theorem was developed by Pearson in 1899 for the purpose of reconstructing stature. Intact long bones of the upper and lower extremities have been subjected to this analysis in Americans (Trotter and Gleser, 1952; 1958), South Africans (Lundy, 1983; Lundy and Feldesman 1987; Dayal, 2002), Portuguese (DeMedonca, 2000), Germans (Mall *et al.*, 2001), Bulgarians (Radoinova *et al.*, 2002) and Turks (Celbis and Agritmis, 2006) for the purpose of stature estimation. Since long bones are not recovered in their intact state in all forensic cases, researchers have also formulated regression equations from the skull (Chiba and Terazawa, 1998; Patil and Mody, 2005; Ryan and Bidmos, 2007), metacarpals (Musgrave and Harneja, 1978; Meadows and Jantz, 1992), measurements of fragments of long bones (Steele and McKern, 1969, Mysorekar *et al.*, 1980, Simmons *et al.*, 1990, Holland, 1992; Chibba and Bidmos, 2007), and the talus and calcaneus (Holland, 1995; Bidmos and Asala, 2005; Bidmos, 2006). Recently, efforts have also been made at estimating stature from measurements of percutaneous bones (Ozaslan *et al.*, 2005), as well as dimensions of the hands, feet and shoe prints (Ozden *et* al., 2005; Krishan and Sharma, 2007; Krishan, 2007).

It is essential that the forensic application of foot bones such as the metatarsals, which have a good chance of being recovered, be investigated. While numerous studies have been conducted on the morphology of metatarsals from clinical and paleoanthropological perspectives, of which Zipfel (2003) provided a detailed account, few researchers have investigated the usefulness of metatarsals for forensic purposes (Byers *et al.*, 1989; Robling and Uberlaker, 1997). Byers *et al.* (1989) made the first and only attempt to date at using the length of metatarsal bones for stature estimation. They used one hundred and thirty skeletons derived from the Terry Collection at the Smithsonian Institute and Maxwell Museum of Anthropology of the University of New Mexico. Six measurements of metatarsals were used for derivation of regression equations for estimation of stature in African and European Americans.

Since no study has been conducted on stature estimation from measurements of metatarsals in South Africans, it was the aim of this study to assess the usefulness of the length of metatarsal bones in the estimation of stature of South Africans of European descent and indigenous population groups.

6.3 MATERIALS AND METHODS

6.3.1 Materials

A total of 226 complete skeletons were selected by a simple random sampling technique from the Raymond A. Dart Collection of Human Skeletons housed in the School of Anatomical Sciences of the University of the Witwatersrand, Johannesburg. In the selection process, consideration was given only to the two biggest groups in the collection namely the indigenous South African (ISA) and South African of European descent (SAED) population groups. While different tribes constitute the ISA population group, they were treated as a single homogeneous group because previous studies have shown that no statistically significant intertribal differences exist in the osteometric dimensions (De Villiers, 1968; Lundy, 1983a).

The SAED population group on the other hand consists of migrants mainly from the Netherlands and other European countries (Steyn and İşcan, 1997). It has been shown that their osteometric characteristics are different from Europeans and American whites (Steyn and İşcan, 1997). The documented ages of selected skeletons ranged between 29 and 75 years. The selected skeletal materials represent 60 ISA males, 53 ISA females, 58 SAED males and 55 SAED females.

6.3.2 Methods

Complete skeletons with elements that constitute stature namely complete skull (with skull cap), vertebrae, femur, tibia, talus and calcaneus were used. Skeletons with missing elements including skull caps, broken edges and those with excessive osteophytic lipping were excluded. For each selected skeleton, total skeletal height (TSH) was estimated using Fully's method (1956) because previous studies by Lundy (1983a) and

Bidmos (2005b) have shown that most documented cadaver lengths that form part of the catalogue of skeletons in the Raymond A. Dart Collection are not reliable.

Measurements that were taken for the calculation of TSH have been described previously in section 3.3.2 (pages 47-60). In addition, six linear measurements of metatarsal bones were taken using a vernier caliper. There are five metatarsal bones in each foot. The first metatarsal is easily recognizable as it is the shortest and thickest; the second is the longest while the fifth is characterized by the presence of a tuberosity (Gray *et al*., 1995). The third and fourth metatarsals are difficult to identify using size as a characteristic as suggested by Gray *et al*. (1995). One important differentiating factor is the presence of two facets on the medial side of the third metatarsal compared to one smooth facet found on the medial aspect of the fourth metatarsal (Gray *et al*., 1995). Measurements of lengths of first to fourth metatarsals were taken using the same technique as described below. However, two length measurements (functional and morphological) were taken of each fifth metatarsal. All these measurements are as defined by Bräuer (1988):

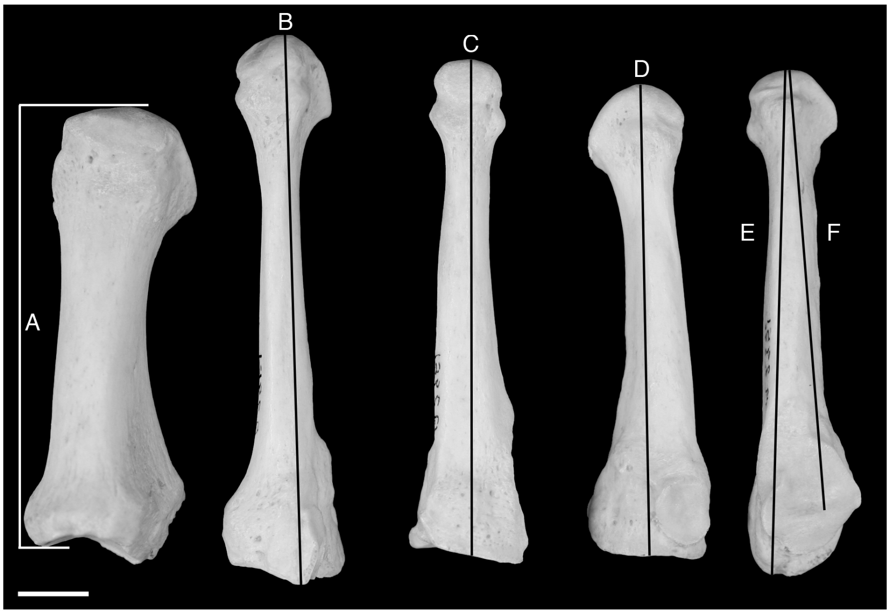
6.3.2.1 Lengths of metatarsals 1-4 (M1- M4)

The linear distance from the apex of the capitulum to the midpoint of the articular surface of the base parallel to the longitudinal axis of the bone (Figure 6.1A –D).

6.3.2.2 Functional length of the 5th metatarsal (M5$_F$)

The linear distance between the apex of the capitulum and the dorsoplantar midpoint of the intersection between the fourth metatarsal and cuboid facets (Figure 6.1E).

Figure 6.1 Measurement of the lengths of metatarsals: First metatarsal (A), Second metatarsal (B), Third metatarsal (C), Fourth metatarsal (D), Functional length of the fifth metatarsal (E) and Physiological length of the fifth metatarsal (F).


A
B
C
D
E
F

6.3.2.3 Morphological length of the 5th metatarsal ($M5_P$)

The linear distance between the apex of the capitulum and the tip of the tuberosity (Figure 6.1F).

6.3.3 Analysis of data

Means and standard deviations for TSH and metatarsal measurements were obtained for each group. Regression analyses were then performed in stages after establishing that (i) data for each group followed a normal distribution pattern, (ii) variances did not show significant sex differences; and (iii) all measurements displayed high reliability. TSH was regressed on individual and various combinations of lengths of metatarsals. From these analyses, the correlation coefficient (r), standard error of estimate (SEE), regression coefficient and constant were obtained. Simple and multiple regression equations were formulated from the coefficients and constants.

6.4 RESULTS

6.4.1 Descriptive statistics

Means and standard deviations for total skeletal height (TSH) and each of the metatarsal measurements for ISA and SAED are presented in Tables 6.1 and 6.2 respectively. Males consistently presented with higher mean values compared to females ($p \leq 0.0001$) with regard to TSH and all metatarsal measurements.

6.4.2 Regression analysis

Tables 6.3 and 6.4 show regression equations that can be used in the estimation of stature from individual lengths of metatarsals for the ISA and SAED population group respectively. In the ISA group, moderate positive correlation was obtained between all measurements and TSH in the male sample (0.44 – 0.62) while females presented with moderate to high correlations (0.54 – 0.72) (Table 6.3). In the SAED group, the range of correlation obtained for males (0.58 – 0.70) was similar to that obtained for females (0.62 – 0.73). M2 to M4 consistently showed high correlation in all groups except for the male ISA sample. The lowest correlation (0.44) was obtained in this group for M4 while the highest correlation of 0.73 was shown by M1 in the SAED female sample (Table 6.4).

The lowest standard error of estimate was obtained for the equation that utilized M2 in the ISA male group (4.14) while that for physiological length of M5 in the ISA female group (5.80) presented with the highest value of SEE (Table 6.3). The standard error of estimate for these equations ranged between 4.14 for ISA males (function 2) and 5.80 for ISA females (function 6). In estimating stature from equations presented in Tables 6.3 and 6.4, it is advised that equations with high correlation coefficients and low standard errors of estimate should be used for each biological group. Regression equations presented for M2 in all groups consistently fit this profile.

Presented in Tables 6.5 and 6.6 are the best multivariate equations with reasonable application for ISA and SAED population groups respectively. A higher range of correlation coefficient (0.67 – 0.76) and lower standard error of estimate (3.81 – 5.07) were obtained which indicates a higher degree of accuracy of regression equations derived from combination of measurements.

Table 6.1 Descriptive statistics for skeletal heigth and measurements of metatarsa in indigenous South Africans

	Males			Females				
Measurements	N	Mean	Std Dev	N	Mean	Std Dev	F-statistic	p-value
TSH	60	153.10	5.25	53	142.60	6.82	85.143	0.000
M1	60	63.14	3.40	53	59.89	3.78	22.587	0.000
M2	60	75.56	3.41	53	71.11	4.30	37.810	0.000
M3	60	70.51	3.65	53	68.00	4.52	10.620	0.001
M4	60	71.26	3.61	53	66.08	4.42	46.962	0.000
$M5_f$	60	61.44	3.35	53	58.53	4.14	17.029	0.000
$M5_p$	60	72.13	4.54	53	68.61	5.35	14.311	0.000

TSH = Total skeletal height, M1 – M4 = Length of metatarsals 1 to 4, $M5_f$ = Functional length of fifth metatars

$M5_p$ = Physiological length of fifth metatarsal

Table 6.2 Descriptive statistics for skeletal heigth and measurements of metatarsa in South Africans of European Desce

	Males			Females				
Measurements	N	Mean	Std Dev	N	Mean	Std Dev	F-statistic	p-value
TSH	58	157.65	6.919	55	147.11	6.13	73.153	0.000
M1	58	62.94	4.39	55	59.98	3.22	16.555	0.000
M2	58	76.41	5.04	55	72.29	4.16	22.326	0.000
M3	58	71.64	4.75	54	67.85	4.22	19.815	0.000
M4	58	70.10	4.64	54	65.90	4.16	25.304	0.000
$M5_f$	58	62.30	4.73	55	59.05	3.92	15.723	0.000
$M5_p$	58	73.05	5.02	55	68.50	5.27	22.094	0.000

TSH = Total skeletal height, M1 – M4 = Length of metatarsals 1 to 4, $M5_f$ = Functional length of fifth metatars
$M5_p$ = Physiological length of fifth metatarsal

Table 6.3 Equations for stature estimation (in cm), correlation and standard error of estimate using individual measurements of metatarsals in indigenous South Africans

	Equations	Correlation	SEE
	Male		
1	0.96M1 + 92.67	0.62	4.16
2	0.96M2 + 80.62	0.62	4.14
3	0.87M3 + 91.75	0.60	4.22
4	0.64M4 + 107.42	0.44	4.76
5	$0.83M5_F + 102.31$	0.53	4.50
6	$0.68M5_P + 103.92$	0.59	4.28
	Female		
1	1.30M1 + 64.97	0.72	4.79
2	1.13M2 + 61.99	0.72	4.81
3	1.05M3 + 71.04	0.70	4.94
4	1.03M4 + 74.50	0.67	5.12
5	$1.03M5_F + 82.43$	0.62	5.38
6	$0.69M5_P + 95.39$	0.54	5.80

Table 6.4 Equations for stature estimation (in cm), correlation and standard error of estimate using individual measurements of metatarsals in South Africans of European Descent

	Equations	Correlation	SEE
	Male		
1	$0.91M1 + 100.49$	0.58	5.71
2	$0.96M2 + 84.00$	0.70	4.97
3	$0.98M3 + 87.41$	0.67	5.16
4	$0.98M4 + 88.65$	0.66	5.24
5	$0.96M5_F + 97.73$	0.66	5.26
6	$0.83M5_P + 97.19$	0.61	5.54
	Female		
1	$1.39M1 + 63.57$	0.73	4.22
2	$1.07M2 + 69.98$	0.72	4.28
3	$1.01M3 + 78.78$	0.69	4.54
4	$1.00M4 + 81.00$	0.68	4.56
5	$0.97M5_F + 89.89$	0.62	4.86
6	$0.74M5_P + 96.61$	0.63	4.79

Table 6.5 Equations for stature estimation (in cm), correlation and standard error of estimate using combination of measurements of metatarsals in indigenous South Africans

	Equations	Correlation	SEE
	Male		
1	$0.64M1 + 0.39M5_P + 85.07$	0.67	3.96
2	$0.58M1 + 0.99M2 - 0.52M4 + 79.44$	0.69	3.92
3	$0.54M1 + 0.75M2 - 0.61M4 + 0.35M5_P + 81.15$	0.71	3.81
4	$0.53M1 + 0.68M2 + 0.21M3 - 0.54M4 - 0.33M5_F + 0.43M5_P + 81.66$	0.72	3.85
	Female		
1	$0.81M1 + 0.53M3 + 58.21$	0.75	4.58
2	$0.81M1 + 0.70M3 - 0.17M5_P + 58.46$	0.76	4.60
3	$0.71M1 + 0.34M2 + 0.49M3 - 0.20M5_P + 56.54$	0.76	4.62

Table 6.6 Equations for stature estimation (in cm), correlation and standard error of estimate using combination of measurements of metatarsals in South Africans of European Descent

	Equations	Correlation	SEE
	Male		
1	$0.71M2 + 0.31M5_F + 83.69$	0.71	4.96
2	$0.58M2 + 0.31M5_F + 0.17M5_P + 81.90$	0.71	4.98
3	$0.78M2 - 0.50M4 + 0.47M5_F + 0.28M5_P + 82.61$	0.72	4.98
4	$0.02M1 + 0.87M2 - 0.29M3 - 0.35M4 + 0.49M5_F + 0.30M5_P + 82.27$	0.72	5.07
	Female		
1	$0.81M1 + 0.53M2 + 60.32$	0.75	4.10
2	$0.84M1 + 0.65M2 - 0.16M5_F + 59.92$	0.76	4.12
3	$0.85M1 + 0.59M2 - 0.38M5_F + 0.22M5_P + 61.92$	0.76	4.14

6.5 DISCUSSION

Trotter and Gleser (1952, 1958) conducted arguably the biggest studies on stature reconstruction. They (1952, 1958) concluded that since regression equations are population and sex-specific, anthropologists should limit the use of such equations to the population and sex groups from which the equations were derived. Many other studies are in agreement with this observation (e.g. Steele and McKern, 1969; Musgrave and Harneja, 1978; Lundy, 1983; Lundy and Feldesman, 1987; Meadows and Jantz, 1992; Holland, 1995; De Medonca, 2000; Dayal, 2002; Bidmos and Asala, 2005). Contrary to the widely accepted recommendation of Trotter and Gleser (1952, 1958), Byers *et al.* (1989) presented equations for combined data for male, female and all samples in addition those derived for each biological group. They combined data for Afro-American (n= 9) and Euro-American (n= 57) males to derive a common equation for males. A similar procedure was carried out for Afro-American (n=7) and Euro-American (n= 49) females. Finally, they combined data for the four biological groups in an attempt to derive a single equation for stature estimation for Americans of both population groups and sexes.

This effort can be justified in a situation where only metatarsal bones are available for forensic analysis. Since this is a very unlikely situation, the reason for deriving such equations is unknown. Since the distribution of sample size in the study (1989) has a greater preponderance of Euro-American individuals, it will therefore render the combined equation biased towards that population group. It can be inferred that if there is a statistically significant difference between mean measurements for the two population groups for each sex, the equations will significantly overestimate or underestimate stature of the Afro-American group. Since the authors (1989) failed to present descriptive statistics for samples used, no comparison could be made between the biological groups they studied and samples used in the present study. A comparison of mean measurements of metatarsal lengths (Tables 6.1 and 6.2, pages 136 and 137) showed statistically significant sex differences for each population group. This is in support of observations made from previous studies on foot bones (Holland, 1995; Bidmos and Asala, 2005; Bidmos 2006) thereby confirming sexual dimorphism of metatarsals.

Byers *et al*. (1989) reported moderate to strong relationships between metatarsal lengths and stature with correlation coefficients that ranged between 0.59 and 0.89. Most of these coefficients were greater than 0.60. A similar result was obtained in the present study. All metatarsal lengths showed a moderate to strong correlation with TSH except M4 (ISA male) and $M5_P$ (ISA male and female) that presented with coefficient of less than 0.6. The accuracy of regression equations from Byers *et al.* (1989) study and the present study are also worth comparing.

The accuracy of a regression equation in the estimation of stature depends on the value of its standard error of estimate (SEE). This is defined as a measure of the expected accuracy of a regression equation in the estimation of the stature of an individual from the same population group from which the equation was originally derived. A high value for SEE suggests a low accuracy and vice versa. The range of SEE for regression equations for estimation of stature using individual metatarsal lengths in ISA males (Table 6.3, page 138) was similar to that obtained for SAED females (Table 6.4, page 139). These equations presented with lower SEEs compared with those obtained for ISA females (Table 6.3, page 138) and SAED males (Table 6.4, page 139). The range of SEEs from multivariate equations (3.81 – 5.07) was slightly lower than that obtained for univariate equations (Tables 6.5 and 6.6, pages 140 and 141). Therefore, regression equations derived from combinations of measurements will present better accuracy compared to those formulated from single variables.

In Byers *et al.*'s (1989) study, the best accuracy was obtained for regression equations that utilised M3 for the African American female group (3.99) while the lowest accuracy was obtained for the regression equation using M5 (functional) for the combined data group (7.6). This range is higher than that obtained in the present study (3.81 – 5.80) which indicates a better predictive accuracy of equations derived in this study. Also, the SEEs obtained from previous studies in South Africa for the calcaneus (4.0 – 6.3), fragments of tibia (5.2 – 6.7) and skulls (4.4 – 6.2) were higher than those found in the present study. However, regression equations derived for intact long bones (SEE for ISA = 1.8 – 5.3, SEE for SAED = 1.8 – 5.5) will provide a more accurate estimate of stature compared with those formulated in this study.

6.6 CONCLUSION

Lengths of metatarsals showed moderate to high correlation with total skeletal height which indicates a good association between predictor and dependent variables. Standard error of estimate for derived regression equations is lower than those obtained for the skull, fragments of tibia and the calcaneus which shows that metatarsals have a better predictive efficacy in stature estimation compared to these skeletal elements. Since SEE of regression equations derived for intact long bones is lower than that presented in the present study, it is recommended that stature should be estimated from these bones when they are available for forensic analysis. In their absence, regression equations presented in this study can provide a reliable estimate of stature.

6.7 Summary of chapter

Only one study has investigated the potential of metatarsals in the estimation of stature for forensic purposes to date. The morphology of these bones from clinical and paleontological perspectives is well researched in different parts of the world including South Africa. In this study, 226 complete skeletons of indigenous South Africans and South Africans of European Descent were used in the formulation of univariate and multivariate regression equations from 6 linear measurements of the metatarsal. The standard error of estimate for these equations was lower than that obtained for other skeletal elements studied so far for stature estimation in South Africans with the exception of intact long bones and fragments of femur (presented in chapters 3 and 4). Therefore, regression equations presented in this study can also provide a reliable estimate of stature in cases when intact long bones and fragments of the femur are not available for forensic analysis

Chapter Seven

Soft Tissue Correction Index for Estimation of Living Stature using Magnetic Resonance Imaging

7.1 Preamble

It has been established in the previous chapters that measurements of fragments of the femur and lengths of metatarsal bones can give a reliable estimate of skeletal height. It is essential that a soft tissue correction index should be added to skeletal height in order to obtain an estimate of living stature. Fully's (1956) soft tissue correction indices that were formulated for different ranges of skeletal height remain the most widely used for this purpose. While some anthropologists consider Fully's method to be the most reliable method of stature estimation, some consider it to be inadequate as it underestimates living stature possibly due to an error in the magnitude of Fully's soft tissue indices. A recent study by Raxter and co-workers revised Fully's technique and also presented a new "universally applicable" soft tissue correction index. The present chapter examines the reliability of soft tissue correction indices of Fully (1956) and Raxter *et al*. (2006) on a living sample of indigenous South African males.

7.2 INTRODUCTION

There has been substantial debate regarding the merits and demerits of the two most widely used methods of stature estimation (e.g. Lundy, 1985). The mathematical method of stature estimation is based on the regression of measurements of bones, especially the long bones of the lower extremities, on stature (Hens *et al.*, 1998; Konigsberg *et al*. 1998). This method is quick, uncomplicated and does not require the entire skeleton for the reconstruction of stature; however, the equations derived from this approach are population and sex specific (Krogman and Iscan, 1986). In addition, these formulae are affected by temporal changes, or secular trends, and as such must be revised periodically (Trotter and Gleser, 1958).

In response to these cautions on stature estimation using regression equations, numerous studies have since been published in different parts of the world as documented in chapter two (Dupertuis and Hadden, 1951; Trotter and Gleser 1952, 1958; Lundy and Feldesman, 1987; Dayal *et al*., 2009). The sources of data for stature from these studies include documented living stature from military records (e.g. Trotter and Gleser, 1958), cadaver lengths (e.g. Radoinova *et al*., 2002), and measured living stature (e.g. Krishan, 2008a & b). In South Africa, studies on stature reconstruction were conducted on skeletons from the Raymond A. Dart Collection of Human Skeletons (Dayal *et al.*, 2009) and the Pretoria Bone Collection (L'Abbé *et al*., 2007). However, due to the unreliability of some of the documented cadaver lengths in these collections, researchers involved in stature reconstruction in South Africa have all, to date, relied on the anatomical method for the estimation of stature.

The anatomical or Fully's method requires the presence of a complete or almost complete skeleton and involves the calculation of skeletal height from the sum of the height of the skull and vertebral column, length of the long bones of the lower extremity and the height of the talus and calcaneus (Fully, 1956; Fully and Pineau, 1960; Lundy, 1983). In order to compensate for soft tissue of the scalp, intervertebral discs, joint cartilages, and soft tissue of the soles of the feet, Fully (1956) also devised correction indices that when added to skeletal height will give an estimate of living stature. Some anthropologists like Stewart (1979) as cited by Raxter *et al*., (2006), Lundy (1985, 1988), Sciulli *et al*. (1990), Sciulli and Giesen (1993) and Ousley (1995) consider Fully's technique to be the best and most accurate method of stature estimation.

Raxter *et al*., (2006) reported that Snow and Williams (1971) conducted the earliest study to assess the accuracy of Fully's method (1956), which Snow and Williams (1971) employed in a forensic case to estimate the stature of a 45 year old white American male. Snow and Williams (1971) observed that the mean of the antemortem stature of the individual was in close agreement with that obtained using Fully's method (Raxter *et al*., 2006). This observation was supported by the findings of Lundy (1988) who applied Fully's method to estimate living stature of three white American servicemen who died in the Vietnam War. Sciulli *et al*. (1990), in agreement with Lundy (1988), used Fully's technique in the formulation of regression equations for the estimation of stature of Prehistoric Native Americans from Ohio, and concluded that: "…the stature estimates of the prehistoric individuals in our sample derived from skeletal heights and soft tissue correction should be the best valuable estimates" (Sciulli *et al*., 1990: page 279). Ousley (1995) provided a further confirmation to the accuracy of Fully's method when he argued that since Fully's technique incorporates all the components of the skeleton that constitute stature, it should provide the best possible estimate of biological stature.

In contrast to these studies, more recent studies by King (2004), Bidmos (2005) and Raxter *et al.* (2006), that utilized bigger sample sizes, are in disagreement with the views expressed by Stewart (1979), Snow and Williams (as reported by Raxter *et al.*, 2006) and Lundy (1988). King (2004) studied 36 complete skeletons of American whites and blacks that were derived from the William M. Bass Collection, University of Tennessee, Knoxville, and observed that Fully's method consistently underestimated stature. In a similar study, Bidmos (2005b) assessed the accuracy of Fully's technique (1956) by examining 156 complete skeletons of South Africans obtained from the Dart Collection and noted that estimates of stature from the use of Fully's method (1956) were consistently lower than documented cadaver lengths. Since the difference was more marked in the indigenous South African population group compared with South Africans of European descent, Bidmos (2005b) suggested that Fully's soft tissue correction indices might be population specific.

The findings of the Raxter *et al.* (2006) study conducted on samples of skeletons (n = 119) obtained from the Terry Collection housed in the Smithsonian Institute, Washington DC were in agreement with those of King (2004) and Bidmos (2005) with regards to underestimation of stature using Fully's technique (1956). Raxter *et al*. (2006) revised Fully's technique and suggested that maximum height of vertebral bodies should be used in the calculation of total skeletal height instead of the anterior body height as instructed by Lundy (1985). In addition, Raxter *et al*. (2006) calculated an overall correction factor for skeletal height that led to the formulation of new correction indices; however, certain pertinent questions still need answers. How accurate are the new correction indices of Raxter and co-workers (2006)? Are these correction indices universally applicable as suggested or are these indices population specific? To address these issues, the present study aims to assess the accuracy of the correction factors of Fully (1956) and Raxter *et al.* (2006) using magnetic resonance imaging (MRI) on a sample of living indigenous South African males.

7.3 SUBJECTS AND METHODS

7.3.1 Sample selection

Indigenous South African males who are members of staff of the Faculty of Health Sciences of the University of the Witwatersrand and Wits-Donald Gordon Medical Centre were invited to participate in this study. Each subject was verbally informed about the design and aim of the study. Those who agreed to participate in the study were thereafter given an Information Leaflet and Informed Consent document (Appendix V) to study and append their signatures as a confirmation of their willingness to participate in the study.

Out of more than fifty individuals that were approached, 32 individuals volunteered and participated in the study. 28 of the participants were used in the final analysis while the remaining 4 subjects were eliminated for various reasons. The length of the femur of subject 1 could not be measured while subject 15 was too tall which made the scanning of his lower limbs bones impossible as he could not fit into the scan machine. Subjects 28 and 32 apparently moved in the course of the scan which resulted in poor quality images that were not suitable for data acquisition.

7.3.1.1 Consideration for population group

The indigenous South African population group consists of different tribes. This include Tswana, Northern Sotho, Southern Sotho, Pedi, Venda, Xhosa, Zulu, Swazi and Ndebele to mention a few. Members of this population group were selected for this study for the following reasons:

(1) It is the biggest of the four population groups that are officially recognized in South Africa;

(2) This group is arguably more exposed to and vulnerable to crime and are more likely to be victims of crime compared to other population groups;

(3) Due to a lack of reliable data to accurately calculate soft tissue correction factors for stature estimation, there is a great need to conduct the study on this population group.

De Villiers (1968) observed that there are no significant intertribal differences in the metrical and non-metrical features of the skull of members of this group. Subsequently, findings of De Beer Kaufman (1974) on the vertebral column and Lundy (1983) on long bones of the upper and lower extremities confirmed the homogeneity of this population group. The issue of inconsistency in self identification by members of this group is problematic. This is as a result of confusion stemming from an inability to separate “biological” from “ethnic” identity (Morris, 2000).

In the course of the present study, this observation was put to test whereby subjects were asked for their tribal affiliation. In response, subjects who are offsprings of intertribal unions or marriages often identify with their maternal tribe in cases where both parents were separated. For the above mentioned reasons, the different tribes that constitute the indigenous South Africans were considered to belong to the same homogeneous group in this study.

7.3.1.2 Consideration for sex

Only males were included in this study. Females were not included for two reasons:

(i) The previous study by Fully (1956), with which the current study will be compared with, was conducted on males only.

(ii) Females of reproductive age may be reluctant to participate in the study because of the potential risk of adverse effects on the fetus and uterus.

7.3.1.3 Consideration for Age

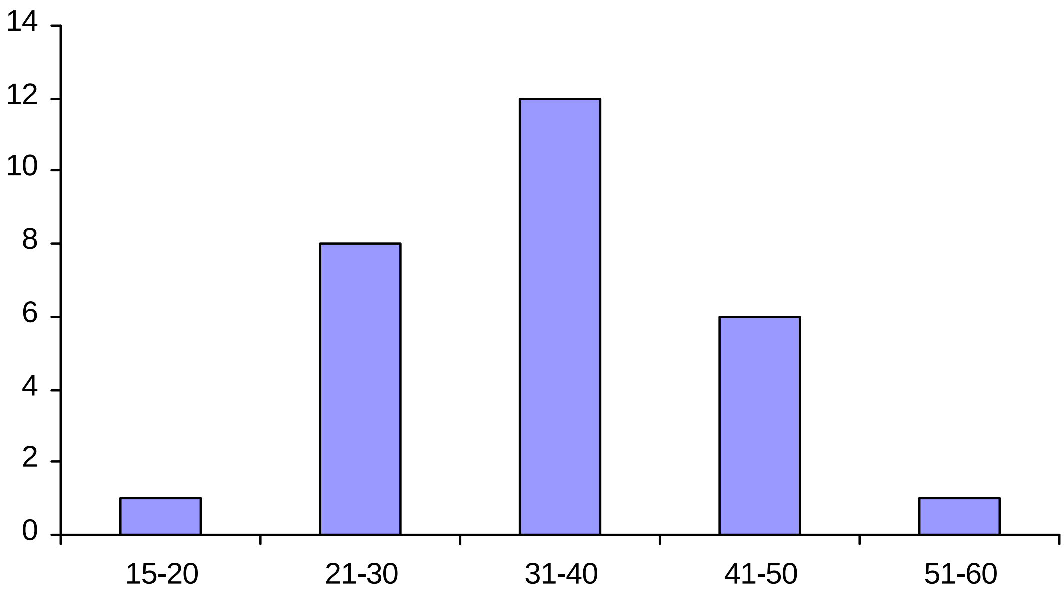
The lower limit of the age bracket for this study was chosen as 18 years because Trotter and Gleser (1958) indicate that an adult reaches maximum stature by this age. The upper limit was 60 years in order to avoid excessive stature loss due to ageing (Trotter and Gleser, 1951). The mean age for subjects used in this study is 34.7 years (range 18 – 56) (Table 7.2). An illustration of the frequency distribution of the age ranges is shown in Figure 7.1. It can be noted that a larger percentage of the subjects were within the 20-40 years age bracket.

7.3.2 METHODS

7.3.2.1 Measurement of living stature

Standing height of each individual was measured using a fixed Stadiometer that is located in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg. Each subject was requested to remove his shoes. Thereafter, the subject was directed towards the stadiometer, with heels close together and back and gluteal region firmly placed against the measuring board. The subject was then requested to inspire a full breadth and thereafter relax in order to obtain full height measurement while standardizing body posture. This protocol is in line with the recommendation of the International Organization for Standardization of 1996 as cited by Steyn and Smith (2007). In order to give consideration to the well documented diurnal variation of stature (e.g. Sjovold, 2002, Krishan, 2008b); living height measurement was taken for all individuals between 10.00 and 10.30 am.

Figure 7.1 Frequency distribution of age ranges for Subjects


14
12
10
8
6
4
2
0
15-20
21-30
31-40
41-50
51-60

7.3.2.2 Acquisition of MRI scans

Full body Magnetic Resonance Imaging (MRI) scans was carried out at the Department of Radiology of the Wits-Donald Gordon Medical Centre Johannesburg for all subjects. Exclusion criteria for this procedure include the presence of cardiac pacemakers and brain implants. In addition, subjects who had pins and plates inserted following fracture to any of the limb bones were excluded from the study. Subjects were then requested to remove their clothes and shoes with the exception of their underwear and were asked to dress in gowns provided by the Radiology department. They were then led to the MRI room and requested to lie down in the supine position.

The subjects were scanned on a 1.5 Tesla Phillips Entera MR scanner with software version 12.1. After a sagittal T1 weighted survey a MOBI track scan (registered Phillips Medical System Holland) was obtained from the head to lower limbs using three stations and using a 3 mm T2 weighted coronal sequence (TR 3500 milliseconds two signal averages). The field of view was 485 cm. To obtain the remaining part of the lower limb, an additional one-station scan was obtained using the same sequence from the feet upwards. The three MOBI track stations were then fused on both survey and T2 scans for further manipulations.

7.3.2.3 Definition of measurements

The measurements described below were carried out on each scan using the freely available OSIRIX software:

7.3.2.3.1 Skull height

The maximum vertical length between the most superior aspect of the skull (excluding the scalp) to the midpoint of an imaginary line that runs across the external aspect of the foramen magnum (Figure 7.2A);

7.3.2.3.2 Height of the second cervical vertebra C2

The maximum linear distance between the tip of the odontoid process to the midpoint of the inferior margin of the body of C2 (Figure 7.2B);

7.3.2.3.3 Maximum height of C3 to L5

Linear measurements were taken from both the anterior and posterior aspect of each vertebra from the third cervical to the fifth lumbar vertebra. The maximum height from either of the two measured aspects was recorded and used as part of the computation for the total skeletal height (Figure 7.3C, T and L)

Figure 7.2 Measurement of the skull height (A) and height of the second cervical vertebra (B), scale = 5 cm

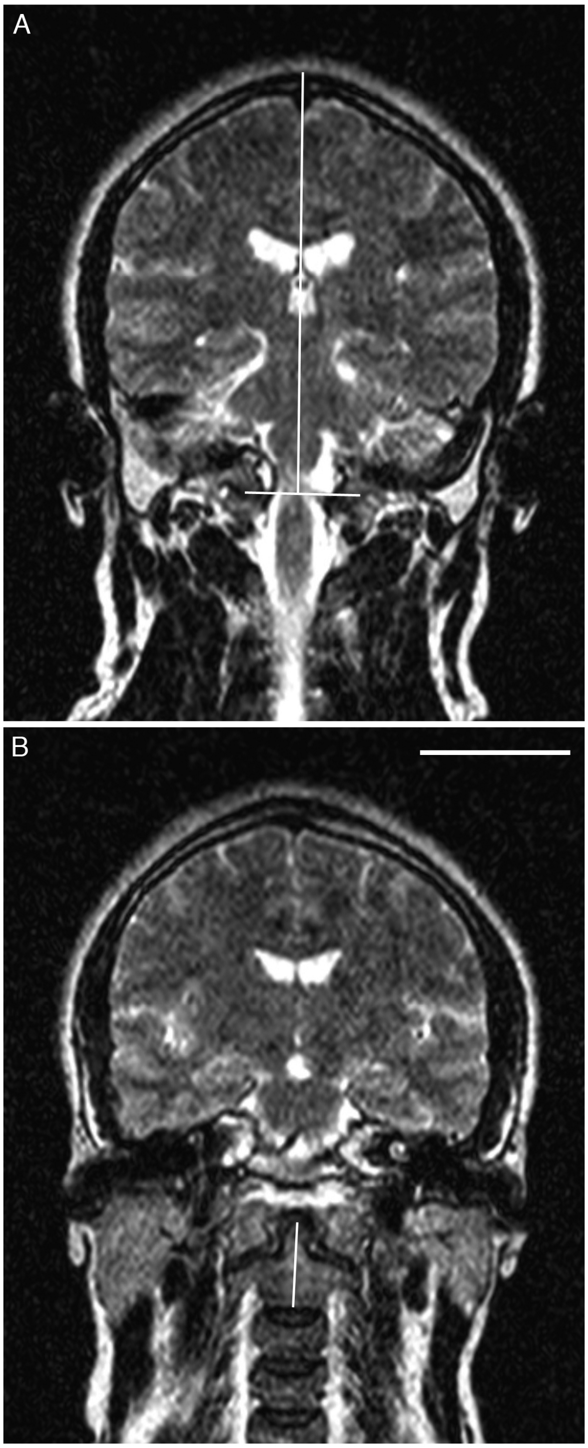

A
B

Figure 7.3 Measurement of the maximum height of cervical (C), thoracic (T), lumbar (L) series and the first sacral vertebra (S), scale = 5 cm


C
T
L
S

7.3.2.3.4 Height of the first sacral vertebra

The maximum height on the anterior aspect of the first sacral vertebra from the level of the sacral promontory to the inferior aspect of S1 was considered as the height of S1 (Figure 7.3S)

7.3.2.3.5 Physiological height of the femur

A line was drawn across the inferior margin of the medial and lateral condyles of the femur. A line representing the physiological length of the femur was drawn from the midpoint of this line to the superior aspect of the head of the femur (Figure 7.4);

7.3.2.3.6 Medial condylomalleolar height of the tibia

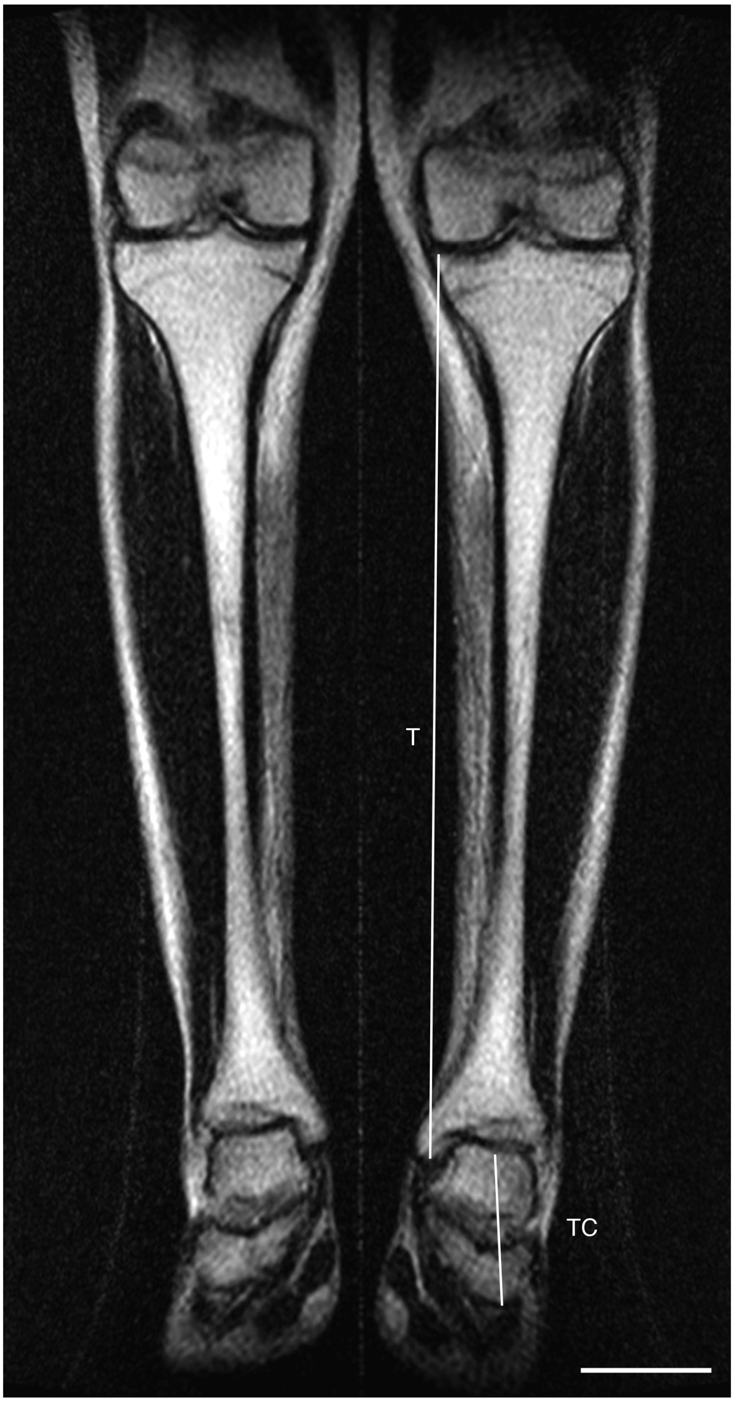
This is represented by the line drawn from the superior aspect of the medial condyle of the tibia to the tip of the medial malleolus (Figure 7.5T); and

7.3.2.3.7 Talocalcaneal height

This is the linear distance from the superior aspect of the talus to the most inferior aspect of the calcaneus (Figure 7.5TC)

Figure 7.4 Measurement of the physiological height of the femur, scale = 5 cm

Figure 7.5 Measurement of the medial condylomalleolar height of the tibia (T) and talocalcaneal height (TC), scale = 5 cm


T
TC

The sum total of all these measurements, the addition of skull height, maximum height of C2 to S1, physiological height of the femur, medial condylomalleolar height of the tibia and the talocalcaneal height, provided an estimate of the total skeletal height.

7.3.2.4 Test of Reliability

Each of the measurements listed below was taken at least twice 24 hours apart in order to standardize the measuring technique: the skull height, height of second cervical vertebra, height of the seventh cervical vertebra (representing the cervical series), height of the tenth thoracic vertebra (representing the thoracic series), height of the fifth lumbar vertebra (representing the lumbar series), sacral height, physiological height of the femur, medial condylomalleolar height of the tibia and talocalcaneal height. In addition, the measured living stature of 10 of the subjects was repeated twice one week apart. An assessment of the reliability of the measuring technique used in this study was objectively conducted with the application of Lin's concordance correlation coefficient of reproducibility (Lin, 1989) which was calculated for each measured variable using the formula:

$$P_c = 1-[1/n \sum (y_1-y_2)^2] / [(sdy_1^{\,2}+sdy_2^{\,2}+ (My_1-My_2)^2],$$

where, n= sample size, y_1= first (test) measurement, y_2= second (retest) measurement, sdy_1= standard deviation of the first set of measurements, sdy_2= standard deviation of the second set of measurements, My_1= mean of the first set of measurements, and My_2= mean of the second set of measurements.

7.3.2.5 Statistical analysis

Thereafter descriptive statistics was carried out on the age, measured living stature (LS), total skeletal height (TSH), physiological length of the femur (FL) and condylomalleolar length of the tibia (TL). Scatter plots were generated in order to visualize the degree of association between LS and each of TSH, FL and TL after which correlation between LS and each of these parameters were computed. The appropriate soft tissue index of Fully was added to calculated TSH for each subject and the resultant estimated living stature (LSF) was compared with measured living stature (LS) using paired *t*-tests. The same comparison was made between LS and estimated living stature (LSR) after the addition of the correction index of Raxter *et al.* (2006). Further analyses were then computed to assess the effect of age on decline in stature.

Finally, a new soft tissue correction index was thereafter calculated using regression analysis as suggested by Raxter *et al*. (2006). The accuracy of this new correction factor was also assessed by calculating living stature from skeletal height for each subject using the derived regression equation for soft tissue correction factor. A range of living stature was subsequently obtained by subtracting from and adding one standard error of estimate to the estimated living stature. The number of subjects with measured living stature falling within the calculated range of estimated living stature was expressed as a percentage.

7.4 RESULTS

7.4.1 Test of reliability

Lin's concordance coefficients of reproducibility (P_c) for all measured variables including LS are as show in Table 7.1. The height of fifth lumbar vertebra (which was selected to represent the lumbar series) has the least value of P_c (0.901) while the highest value (0.998) was obtained for the height of the skull (SH). Since these values fall within the recommended range as suggested by Lin (1989), the measuring techniques used in this study can be regarded to be adequate and analyses conducted thereafter are considered free of measurement errors.

7.4.2 Descriptive Statistics

Descriptive statistics including the mean and standard deviation is presented for the living stature (LS), total skeletal height (TSH), femur length (FL) and tibial length (TL) in Table 7.2. Scatter plots showing a linear relationship between (i) LS and TSH, (ii) LS and FL, and (iii) LS and TL are shown in Figures 7.6A-C. It can be seen that LS shows a strong and significantly positive correlation with TSH ($r = 0.934$, $p \le 0.0001$). Similarly, the correlation between LS and each of FL ($r = 0.878$, $p \le 0.0001$) and TL ($r = 0.878$, $p \le 0.0001$) are strong and significantly positive.

7.4.3 Validity of soft tissue correction indices of Fully (1956) and Raxter *et al.* (2006)

For each of the subjects, the appropriate soft tissue index, as directed by Fully (1956), was added to TSH in order to obtain an estimate of LS using Fully's technique (LSF). In addition, an estimate of stature using the correction factor as

Table 7.1 Concordance correlation coefficient of reproducibility

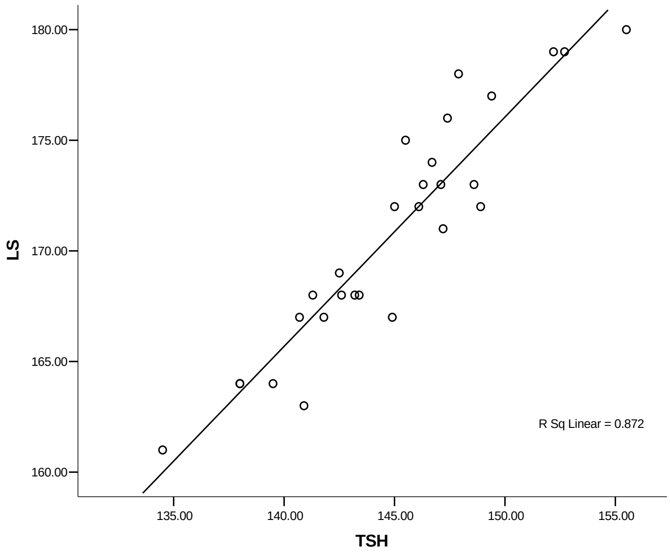
Measurement	P
LS	0.952
SH	0.998
C2	0.986
C7	0.933
T10	0.911
L5	0.901
S1	0.950
FL	0.992
TL	0.997
TCH	0.938

Table 7.2 Mean age (Age), living stature (LS), total skeletal height (TSH), femur length (FL) and tibial length (TL) in Subjects

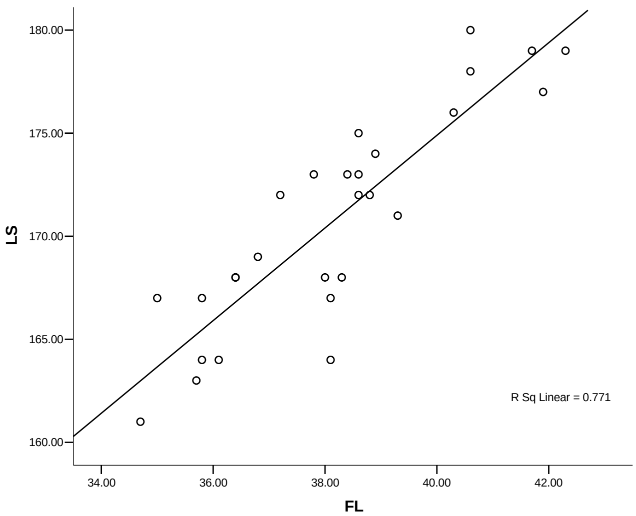
Subject's No	Age	TL/cm	FL/cm	TSH/cm	LS/cm
2	41	38.8	47.1	146.1	172.0
3	33	38.6	46.8	145.5	175.0
4	49	35.7	42.9	140.9	163.0
5	25	40.3	47.7	147.4	176.0
6	45	35.0	43.4	141.8	167.0
7	32	35.8	43.7	144.9	167.0
8	43	36.4	41.6	141.3	168.0
9	40	38.0	42.9	143.4	168.0
10	32	36.4	44.3	142.6	168.0
11	39	41.7	46.7	152.2	179.0
12	28	38.9	48.1	146.7	174.0
13	40	39.3	47.7	147.2	171.0
14	31	38.1	42.9	140.7	167.0
16	24	38.6	45.3	146.3	173.0
17	47	37.2	44.4	145.0	172.0
18	58	38.3	42.7	143.2	168.0
19	38	35.8	43.3	138.0	164.0
20	37	36.8	43.9	142.5	169.0
21	33	36.1	43.3	138.0	164.0
22	25	37.8	46.0	147.1	173.0
23	32	42.3	48.2	152.7	179.0
24	43	41.9	47.6	149.4	177.0
25	27	40.6	47.7	147.9	178.0
26	18	34.7	41.2	134.5	161.0
27	23	40.6	49.7	155.5	180.0
29	21	38.1	44.2	139.5	164.0
30	40	38.4	46.2	148.6	173.0
31	28	38.6	45.6	148.9	172.0
Mean	34.7	38.2	45.2	144.9	170.8

Figure 7.6 Scatter plots of living stature (LS) against **A**: total skeletal height (TSH); **B**: femur length (FL) and **C**: condylomalleolar length (CML).

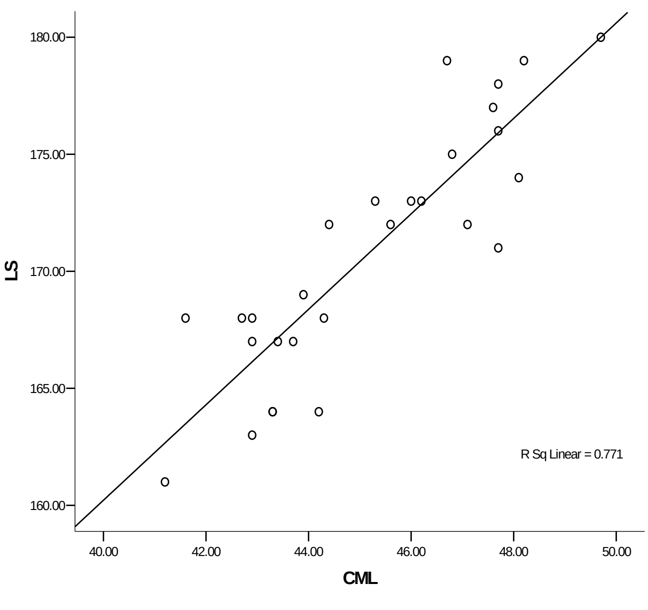
A


LS
180.00
175.00
170.00
165.00
160.00
R Sq Linear = 0.872
135.00
140.00
145.00
150.00
155.00
TSH

B


LS
180.00
175.00
170.00
165.00
160.00
R Sq Linear = 0.771
34.00
36.00
38.00
40.00
42.00
FL

C


LS
180.00
175.00
170.00
165.00
160.00
R Sq Linear = 0.771
40.00
42.00
44.00
46.00
48.00
50.00
CML

suggested by Raxter *et al*., (2006) was calculated (LSR). Even though the correlation between LS and LSF is strong and significantly positive ($r = 0.932$), paired *t*-tests performed reveal that the addition of Fully's correction index to obtain LSF significantly underestimates LS by 15.8cm ($p \leq 0.0001$). Also, the correlation between LS and LSR is strong and significantly positive ($r = 0.934$); however, there is a statistically significant difference (14.8 cm, $p \leq 0.0001$) between the two parameters.

7.4.4 Effect of ageing on decline in stature

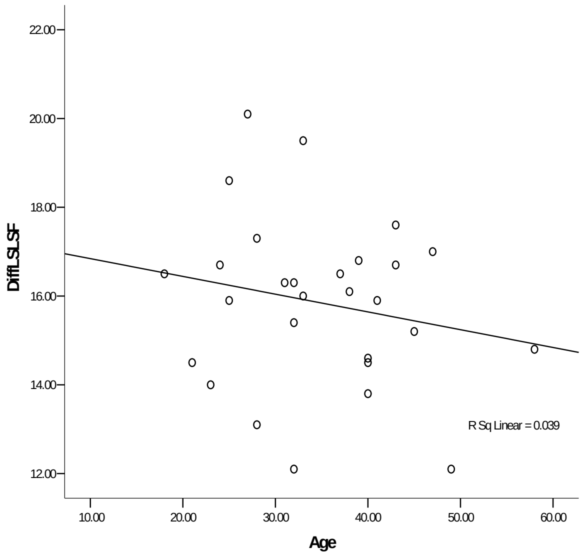
The effect of ageing on decline in stature is assessed by plotting the difference between LS and LSF against age (Figure 7.7). There is a weak positive correlation with age ($r = 0.20$) when age related decline is not factored in (Figure 7.7A). However, when age related decline as suggested by Trotter and Gleser (1952) and Cline *et al.*, (1989) are considered, the correlation are 0.02 and 0.13 respectively (Figures 7.7B and C). A similar result is obtained when the difference between LS and LSR is plotted against age without (Figure 7.8A) and with (Figure 7.8B and C) age related decline. These results indicate that the prediction of living stature is not significantly dependent on age.

7.4.5 Calculation of new soft tissue correction index

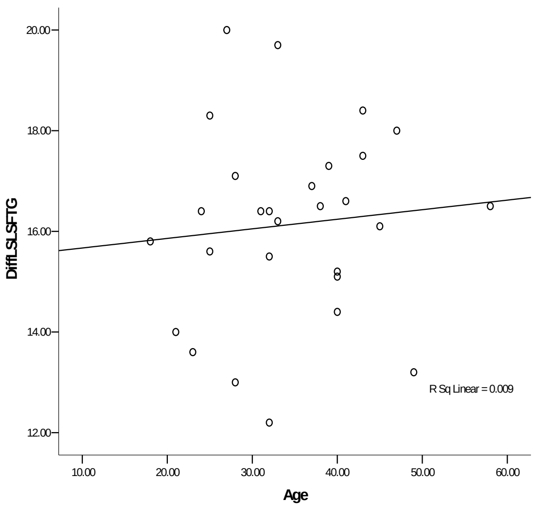
Since the estimate of stature from the use of the correction factor of Fully (LSF) and Raxter *et al*. (LSR) both underestimate LS by a large margin, this suggests that the incorporation of the correction factors of Fully (1956) and Raxter *et al.* (2006) are not appropriate for use in a living sample of indigenous South African

Figure 7.7 Scatter plots of the difference between living stature (LS) and estimated living stature using Fully's soft issue correction indices (LSF) against age when age is not adjusted for (A); when age related decline is adjusted for as suggested by Trotter and Gleser (1952) (B) and Cline *et al*. (1989) (C).

A


22.00
20.00
18.00
16.00
14.00
12.00
DiffLSLSF
R Sq Linear = 0.039
10.00
20.00
30.00
40.00
50.00
60.00
Age

B


20.00
18.00
16.00
14.00
12.00
DiffLSLSFTG
R Sq Linear = 0.009
10.00
20.00
30.00
40.00
50.00
60.00
Age

C

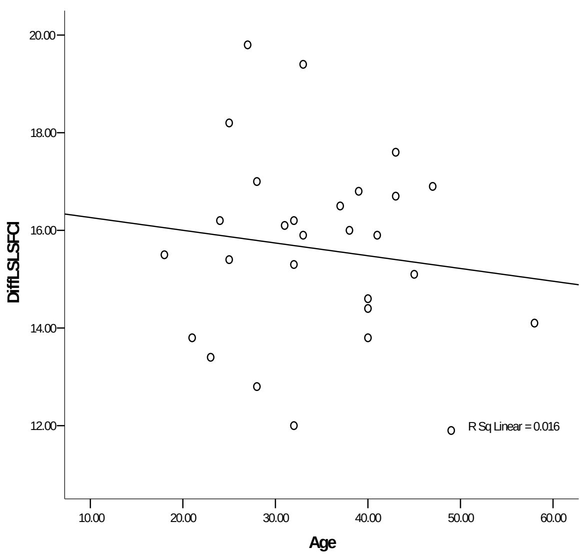
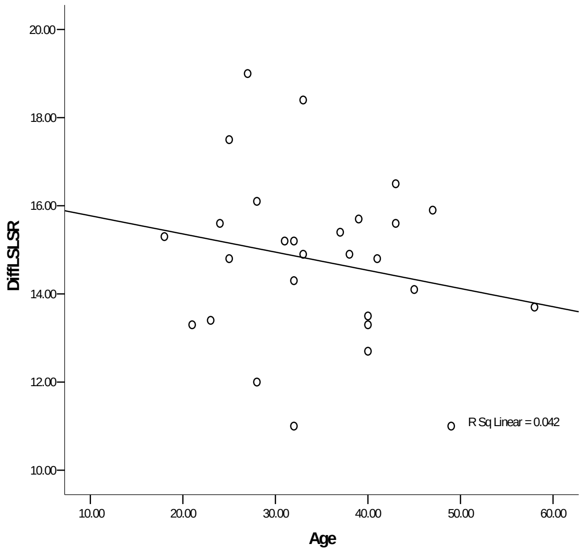
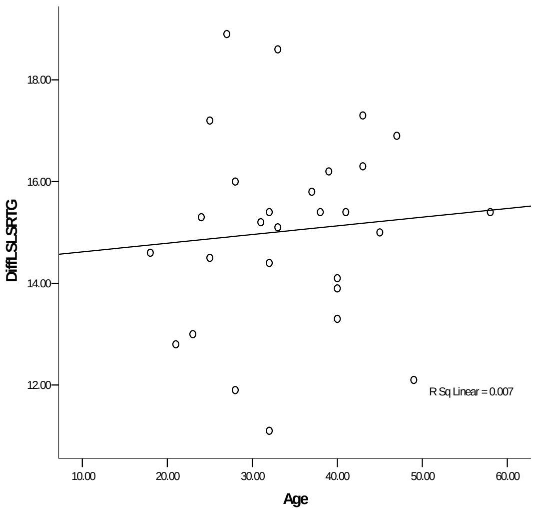

20.00
18.00
16.00
14.00
12.00
DiffLSLSFCI
R Sq Linear = 0.016
10.00
20.00
30.00
40.00
50.00
60.00
Age

Figure 7.8 Scatter plots of the difference between living stature (LS) and estimated living stature using Raxter *et al*. (2006) soft issue correction indices (LSR) against age when age is not adjusted for (A); when age related decline is adjusted for as suggested by Trotter and Gleser (1952) (B) and Cline *et al*. (1989) (C).

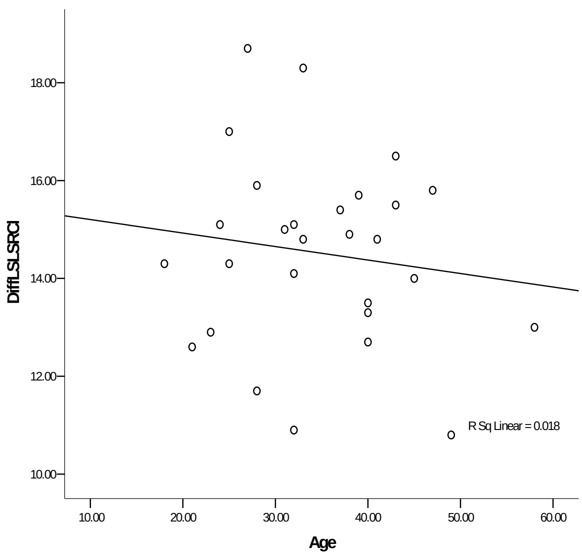
A


20.00
18.00
16.00
14.00
12.00
10.00
DiffLSLSR
R Sq Linear = 0.042
10.00
20.00
30.00
40.00
50.00
60.00
Age

B


18.00
16.00
14.00
12.00
DiffLSLSRTG
R Sq Linear = 0.007
10.00
20.00
30.00
40.00
50.00
60.00
Age

C


18.00
16.00
14.00
12.00
10.00
DiffLSLSRCI
R Sq Linear = 0.018
10.00
20.00
30.00
40.00
50.00
60.00
Age

males. As a result, a new correction index was calculated using regression analysis and it is based on the prediction of living stature from TSH. The equation is given as:

Living stature = 1.037 x TSH + 20.56.

The Pearson correlation coefficient for this equation is 0.934, indicating a high degree of association between skeletal heights using Fully's technique (TSH) and measured living stature (LS). In addition, the standard error of estimate from the use of this equation (1.93) is low which therefore indicates a high accuracy.

7.4.6 Accuracy of soft tissue correction index

Table 7.3 shows the result of the accuracy of stature estimation using the derived regression equation for soft tissue correction factor at 1 standard error of estimate. The estimated living stature falls within 1 SEE in 100% of cases thereby confirming the accuracy of the new soft tissue correction factor.

Table 7.3 Accuracy of soft tissue correction factor

No	Age	TSH/cm	EstLS-1SEE	LS/cm	EstLS+1SEE
2	41	146.1	170.1	172.0	174.0
3	33	145.5	169.5	175.0	173.4
4	49	140.9	164.7	163.0	168.6
5	25	147.4	171.5	176.0	175.3
6	45	141.8	165.7	167.0	169.5
7	32	144.9	168.9	167.0	172.8
8	43	141.3	165.2	168.0	169.0
9	40	143.4	167.3	168.0	171.2
10	32	142.6	166.5	168.0	170.4
11	39	152.2	176.5	179.0	180.3
12	28	146.7	170.8	174.0	174.7
13	40	147.2	171.3	171.0	175.1
14	31	140.7	164.5	167.0	168.4
16	24	146.3	170.3	173.0	174.2
17	47	145.0	169.0	172.0	172.9
18	58	143.2	167.1	168.0	170.9
19	38	138.0	161.7	164.0	165.5
20	37	142.5	166.4	169.0	170.2
21	33	138.0	161.7	164.0	165.6
22	25	147.1	171.2	173.0	175.0
23	32	152.7	177.0	179.0	180.8
24	43	149.4	173.5	177.0	177.4
25	27	147.9	172.0	178.0	175.8
26	18	134.5	158.1	161.0	162.0
27	23	155.5	179.9	180.0	183.7
29	21	139.5	163.3	164.0	167.2
30	40	148.6	172.7	173.0	176.5
31	28	148.9	173.0	172.0	176.9

EstLS = Estimated living stature from skeletal height after the addition of correction factor
1SEE = one standard error of estimate

7.5 DISCUSSION

7.5.1 Critical appraisal of Fully's method and the use of MRI in stature reconstruction

There are a number of ambiguities regarding the definitions of measurements for estimation of skeletal height as directed by Fully (1956). Most notable, and of importance to the present study, are the measurements of the vertebral height and the articulated height of the talus and the calcaneus. Fully (1956) instructed that the total height of each vertebral body (from C2 to S1) should be taken. However, this is different from the subsequent instruction of Fully and Pineau (1960) whereby maximum height of each vertebral body was suggested for measurement. Raxter *et al*. (2006) noted that different authors have varied interpretations of this measurement. For example, Olivier (1969) and Stewart (1979), as cited by Raxter *et al*. (2006), favoured the use of the maximum height of the vertebral body. None of the definitions of Fully (1956) and Fully and Pineau (1960) specifies exactly where the measurement should be taken (Raxter *et al*. 2006). In other words, should the measurements be taken on the anterior or posterior aspect of the body?

Lundy (1983a,b, 1985, 1988) interpreted the measurement as maximum height of each vertebral body and the measurement should be taken on the anterior aspect of the vertebral body. However, this is slightly different from the definition of Lundy and Feldesman (1987) in which there is no specification regarding where the measurement should be taken on the vertebral body. This issue was addressed by Raxter *et al*. (2006) and they recommended that the maximum height of the vertebral body should be measured wherever it occurred on any part of the anterior aspect of the vertebral body. In addition, Raxter *et al*. (2006) observed that the position of the maximum height varies and is often not in the midline contrary to the suggestion of Lundy (1988).

The measurement of the articulated height of the talus and calcaneus also posed a serious challenge as Fully (1956) did not give complete details on how this measurement should be taken, even though he defined it as the distance from the most superior point of the talus to the most inferior point of the calcaneus. Lundy (1988) illustrated the way and manner in which the measurement should be taken. He (personal communication, 2000) directed that the talus and calcaneus of the left side be articulated and placed on an osteometric board or a mandibulometer. The talus should be orientated in such a way as to allow the superior surface of the head to touch the fixed end of the board while the superior surface of the anterior aspect of the talus should be parallel to the board. While keeping the inferior surface of the calcaneus at an inclination angle, the movable part of the osteometric board should be moved to touch the inferior surface of the calcaneus. This description of Lundy (1988) was well illustrated by Raxter *et al.* (2006: Figure 5, page 383). Raxter *et al.* (2006) recommended that the articulated height of the talus and calcaneus should be taken in the manner described by Lundy (1988).

Magnetic resonance imaging is a technique that is primarily used in radiology for visualizing internal structure of the body. It is also useful in the assessment of the function of certain organs of the body (e.g. the brain). It is a powerful technique and is superior to the computed tomography because it provides a greater contrast between different soft tissues of the body. In addition, the amount of ionizing radiation emitted by an MRI machine compared to a CT scanner is minimal and as such patients or subjects are not exposed to hazards of ionizing radiation. These are some of the reasons why this technique has been selected for the current study and I am not aware of any previous study that have been conducted on stature reconstruction with the dual application of MR imaging and Fully's method. The measurement techniques as described by Fully (1956) and interpreted by various authors as discussed above therefore posed some challenges when applied in the current study, specifically skull height, vertebral height, and articulated height of the talus and calcaneus.

Skull height is defined as the linear distance between *bregma* (the junction between the sagittal suture and coronal suture of the skull) and *basion,* which is the most inferior part of the anterior margin of the foramen magnum (Bräuer, 1988). It was practically impossible to determine these two points, i.e. bregma and basion, on the images obtained from the MRI scan. As a result therefore, the definition of the skull height was modified. The maximum linear distance from the most superior point of the skull in the coronal plane to the mid point of an imaginary line that runs between the outermost parts of the foramen magnum was taken to represent skull height.

The measurement of the height of the vertebral body posed a different challenge. The current study was undertaken with due consideration to the suggestion of Raxter *et al*. (2006) regarding measurement of the maximum height of the vertebral body anterior to the pedicles. The measurements could only be taken using the MOBI sagittal view as it was difficult to make comparisons between measurements taken on different slides in the coronal plane so as to obtain maximum height. This is due to the fact that viscera in the mediastinum obscured the vertebral column, especially in the thoracic segment.

The measurement of the articulated height of the talus and calcaneus requires that the sole of the feet should be at a right angle to the body so that the calcaneus will be at the correct inclination angle. One of the limitations of the present study is that it was difficult for subjects to keep their feet in the anatomical position i.e. at right angles to the body. One would expect that this may affect the overall estimate of skeletal height but since the dimension of the articulated height of the talus and calcaneus is small compared to the overall skeletal height, it is assumed that this minimal error should not significantly affect the eventual estimate of skeletal height. Since this measurement was taken on different slices just like other measurements, it was impossible to have a complete visualization of the articulated talus and calcaneus. Therefore, the maximum linear distance from the most superior point of the talus to the most inferior point of the calcaneus was taken as the articulated height of the talus and calcaneus.

7.5.2 Comparison of the methods of evaluation of soft tissue correction indices of Fully (1956) and Raxter *et al*. (2006) with the current study

The estimation of living stature from skeletal height requires that a soft tissue correction index should be added in order to account for soft tissue which Fully (1956: page 270) described as “soft parts, cartilages, intervertebral discs, vertebral curvature, menisci and so on”. However, Lundy (1983a) interpreted the soft tissue of Fully (1956) to include thickness of the scalp and soft tissue of the soles of the feet. Fully (1956) selected 60 of the 102 subjects in his study for the purpose of calculating a soft tissue correction index. The reason for this selection was not stated; but it is presumed that these individuals were of medium height as mentioned in his concluding remarks. Fully (1956) subtracted skeletal height from documented living height and thereafter calculated the mean of the difference that was termed the correction index. For these individuals, a correction index of 10.5 cm was obtained.

Subsequently, Fully (1956) modified this correction index for extreme heights since he noted that the correction index varies with height. It is not clear how this was done.

Raxter *et al*. (2006) re-defined the components of Fully's soft tissue correction factor based on their sample and identified anatomical components that may be responsible for the inaccuracy of Fully (1956) soft tissue correction index. The major component of soft tissue is represented by the sum of the height of the intervertebral discs (Raxter *et al*., 2006). In addition to the components of the soft tissue correction factor as suggested by Fully (1956), Raxter *et al*. (2006) identified other anatomical components which include distance from the basion to the odontoid process, distance from S1 to acetabular roof and the distal projection of tibial medial malleolus. Instead of calculating a new soft tissue index based on these additional components, Raxter *et al*. (2006) recalculated an overall correction index based on total skeletal height using regression analysis. Raxter *et al*. (2006) derived regression equations for the estimation of living stature from skeletal height with known and unknown ages.

Calculation of a new soft tissue correction index for stature estimation in indigenous South African males became necessary since the application of the soft tissue indices of Fully (1956) and Raxter *et al*. (2006) produced estimates of stature that were significantly less than the actual living stature (section 7.4.3, pages 171 & 176). This new soft tissue index was calculated as described by Raxter *et al*. (2006) using regression analysis. The equation thus obtained for living stature estimation as presented above in section 7.4.5 (page 176 & 181) has a low standard error of estimate (1.93) indicating a high accuracy. This is slightly lower compared to that presented for equations 1 (2.22) and 2 (2.31) by Raxter *et al*. (2006: page 378). The correlation coefficient between skeletal height and stature in the current study (0.934) also compares well with those presented for equations 1 (0.956) and 2 (0.952) by

Raxter *et al*. (2006: page 378). The obtained accuracy (100%) from the application of the derived soft tissue correction index to skeletal heights of each subject in the current study is a further confirmation of the accuracy of this new correction factor.

7.5.3 Population specificity of soft tissue correction indices

Analyses of data from the current study reveal that the addition of Fully's (1956) and Raxter *et al*. (2006) correction indices to skeletal height produced estimates of living statures that are significantly lower than measured living statures of indigenous South African males. These observations indicate that the correction indices of Fully (1956) and Raxter *et al*. (2006) are not applicable for the studied subjects. This finding is in support of a previous hypothesis indicating the possibility of population and sex specificity of soft tissue correction indices (Bidmos, 2005) and is in agreement with previous observations made by Lan (1995) and Aulsebrook *et al*. (1996) on soft tissue indices that are applied in forensic facial reconstruction.

Lan (1995) studied living subjects from 15 different nationalities in the Peoples Republic of China by means of facial somatometry, photographs of facial landmarks and X-ray photography. The observed soft tissue indices for the different nationalities were significantly different and revealed regional differences (Lan, 1995). In a similar study, Aulsebrook *et al*. (1996) constructed a table of facial soft tissue thicknesses in adult Zulu males using ultrasonographic and cephalometric radiographic techniques. Aulsebrook *et al*. (1996) noted that the African American population group is characterized by high variability since they are an admixture of different stocks including "African Negroid", European and Native Americans. Therefore, soft tissue indices that were calculated by Rhine and Campbell (1980) for African Americans, Aulsebrook *et al*. (1996) argued, should not be applied to an indigenous South African population group, thereby necessitating the establishment of mean depth values for 54 landmarks of the face of the Zulu male.

Raxter *et al*. (2006) recalculated soft tissue indices that take into account other anatomical components that were not included in the original soft tissue index as calculated by Fully (1956). These indices were calculated using regression analysis on data collected from samples of skeletons of Americans that were derived from the Terry Collection. Researchers in physical anthropology cautioned that regression equations should be limited to the population group from which such equations have been formulated (e.g. Trotter and Gleser, 1952; Holland, 1995). One of the reasons for this caution is due to the fact that human proportions vary greatly between different population groups (e.g. Ruff 1994). Since the calculation of soft tissue correction indices of Raxter *et al*. (2006) were based on regression analysis, this may further explain the lack of agreement between estimate of stature from skeletal height with the use of the soft tissue correction index of Raxter *et al*. (2006) and the actual living stature as measured in the current study.

7.5.4 Comparison of age distribution

The age range of subjects used in the current study (18-58 years) is similar to that of volunteers (18-56 years) in a recent large study on living stature estimates of South Africans by Steyn and Smith (2007). The latter study was based on data collected for ergonomics design from 3415 volunteers, of which 1208 were ISA males. Fully (1956) did not present any information on his sample with regards to the range and mean of age. Consequently, an adequate comparison cannot be made between Fully's study and the current study. This is relevant as it could show whether there is a bias from the current study towards a particular age group as this has consequences on the effect of age on decline in stature. The age range for the Raxter *et al*. (2006) sample (21-85) is wider compared to that used in the present study (18-58). In addition, the mean age from the current study (35 years) is lower compared to that (54 years) presented by Raxter *et al*. (2006). The age differences between the sample used in the current study and those used by Raxter *et al*. (2006) could be one of the reasons for the differences observed regarding population specificity of the soft tissue correction index.

7.5.5 Comparisons between methods of estimating living stature in the present study and previous studies

The mean living stature from the current study (170.8 cm) compares well with that (171.0 cm) obtained by Steyn and Smith (2007) for the ISA male group. Even though the latter study has the advantage of using a bigger sample size compared to that used in the current study, data collected from both studies can be regarded as being new and are therefore representative of the currently living ISA males. Living heights of individuals whose skeletons were used by Fully (1956) in the formulation of soft tissue correction indices were obtained from different sources. These include concentration camp and military records as well as penitentiary archives. Since these measurements were obtained from varied sources, it is presumed that different individuals at the different locations may have taken them and this may lead to errors. The validity of these measured statures is therefore questionable.

Porter (2002: page 18) suggested that "a valid method should include the condition that all measurements should be taken by one or more trained observers using a defined method on fit persons". The question then arises as to how many individuals were involved in the taking of the measurements used by Fully (1956) and what degree of expertise did they possess? Since Fully (1956) did not give any details on how these measurements were taken and by whom, his stature data can be regarded as being "fragile and suspect" (Porter 2002: page 19).

Raxter *et al*. (2006) relied on documented cadaver lengths as contained in the catalogue of the Terry Collection. They (2006) adjusted the cadaveric lengths to living stature by subtracting 2.5 cm as suggested by Trotter and Gleser (1952). This is contrary to the recommendation of 2 cm by other anthropologists (Byers *et al*., 1989; Meadows and Jantz, 1992; Hauser *et al*., 2005). In contrast to these previous studies, statures of subjects used in the current study were measured by one measurer (the investigator). As a result, the inter-observer error which Ousley (1995) considered to be a serious problem with measurement of stature was therefore avoided. This avoidance notwithstanding, it should be borne in mind that measured stature using living subjects is not without its limitations.

Giles and Hutchinson (1991) identified three factors that could affect the accuracy of measured stature. First, since stature fluctuates by as much as 2.4 cm over a 24 hour period, it is therefore dependent on the time of the day when it is taken. In the present study, statures for all subjects were taken at approximately the same time period of the day. Secondly, the accuracy of stature is affected by the mensurational technique, which can be done in either of two ways: (1) by standing against a wall and (2) in the free standing position with the use of an anthropometer. The former technique was used in the present study as it has been shown to be more accurate (Giles and Hutchinson 1991). Thirdly, the degree of variation of measuring technique among measurers may also affect the accuracy of the measured stature; however, Bennett and Osborne (1986) observed that measurers generally find it easy to standardize stature measurements. In fact, the result of the concordance correlation of reproducibility of living stature (0.952) as presented in Table 1 provides further support to the reliability of the measuring technique used in the acquisition of these data. Based on the above, the stature data collected in this study could be considered to be reliable.

7.5.6 Comparison of correlation coefficients

Several studies have indicated that the length of the femur has been shown to give the best correlation with stature (Trotter and Gleser, 1952a, 1958; Hauser *et al*., 2005; Dayal *et al*., 2009); however, other studies observed that the tibia (e.g. Petrovecki *et al*. 2007) and fibula (e.g. Radoinova *et al*., 2002) have the best correlation with stature in the studied sample. Lundy and Feldesman (1987) obtained a correlation of 0.896 between skeletal height and each of the physiological length of femur and condylomalleolar length of the tibia. In the current study, a strong positive correlation was observed between living stature and femur length (0.878) which is in agreement with the observation of Lundy and Feldesman (1987). In addition, a similar magnitude of correlation as for LS and femur length was obtained between LS and tibial length (0.878).

7.6 CONCLUSION

While all previous studies on the reliability of the Fully's method were conducted on samples of cadaver derived skeletons, the current study is based on a sample of a living population and is the first of its kind that has been conducted on stature reconstruction with the dual application of MR imaging and Fully's method. The application of soft tissue correction indices of Fully (1956) and Raxter *et al.* (2006) produced estimates of stature that are significantly lower than measured living statures of a sample of indigenous South African males used in the current study. This suggests that the correction indices of Fully (1956) and Raxter *et al*. (2006) are not applicable for the studied subjects. Consequently, a new soft tissue correction index was formulated with an accuracy of 100% in the correct estimation of stature within 1 standard error of estimate. The reliability of this new correction index needs to be evaluated using an independent sample.

7.7 Summary of chapter

The application of the MR imaging technique in stature reconstruction is very rare. No previous study in physical anthropology has been conducted with the dual application of Fully’s method and MRI. The current study designed for this dual purpose is based on data collected from 28 male volunteers who are members of the indigenous South African population group. Standing height of each subject was measured using a stadiometer. Fully’s method was used in the calculation of total skeletal height from full body MRI scan of each subject. Subsequent analyses of the acquired data revealed that the previously derived soft tissue correction indices are not applicable to the studied sample which necessitated the derivation of a new soft tissue correction index with an accuracy of 100% of statures within 1 standard error of estimate.

Chapter Eight

Concluding Remarks

8.1 Introduction

Stature estimation forms an important component of skeletal analysis in forensic anthropology. Thus, an accurate estimate of stature is crucial for the establishment of a positive identification of an individual whose skeleton is presented for forensic analysis. As a result, numerous studies have been conducted worldwide on stature reconstruction from intact bones which include the skull (Chiba and Terazawa, 1998, Krishna, 2008b), segments of the vertebral column (Tibbetts, 1981; Jason and Taylor, 1995), intact long bones of the upper and lower extremities (Trotter and Gleser, 1952a,b), metacarpals (Musgrave and Harneja, 1978; Meadows and Jantz, 1992), metatarsals (Byers *et al*. 1989) and tarsal elements (Holland, 1995) as described in chapter two. Intact long bones of the upper and lower limbs, especially the femur and tibia, consistently presented with the best correlation with stature (e.g. Trotter and Gleser, 1952a; Munoz *et al*. 2001). Since these bones are sometimes recovered in various forms of fragmentation in forensic cases, efforts were also made in other parts of the world at formulating equations for estimation of stature from measurements of fragments of these bones (e.g. Simmons *et al*. 1990).

Components of the skeleton that have been used for the purpose of stature reconstruction to date in South Africa include the skull (Ryan and Bidmos, 2007), intact long bones of the upper and lower extremities (Lundy, 1983a, b; Lundy and Feldesman, 1987; Dayal, 2002; Dayal *et al*. 2008b), the vertebral column (Lundy and Feldesman, 1987; Dayal *et al*. 2008b), fragmentary tibiae (Chibba and Bidmos, 2007) and the calcaneus (Bidmos and Asala, 2005, Bidmos, 2006). The results of all the studies conducted so far in South Africa indicate that the intact femur presented with the highest correlation (0.896: Lundy and Feldesman, 1987; 0.92 – 0.93 : Dayal *et al*., 2008b) with stature and the formulated regression equations showed the lowest standard error of estimate (2.78 – 2.79: Lundy and Feldesman, 1987; 2.40 – 2.64 : Dayal *et al*., 2008b). To date, no previous studies have been conducted on the usefulness of selected measurements of fragments of the femur in the estimation of stature in South Africa. Chapters three and four addressed this issue with the view of establishing population and sex specific equations for the estimation of stature from fragmentary femora of South Africans.

8.2 Fragmentary femora in stature reconstruction in South Africa

In chapter three, Fully's technique (1956) was used in the calculation of skeletal height for 100 complete skeletons of indigenous South Africans. The skeletal height was subsequently regressed on six measurements taken on the proximal and distal ends of the femur in order to obtain equations for the direct estimation of stature. The indirect method of stature estimation involved the formulation of regression equations for the estimation of maximum length of the femur from measurements of its fragments and subsequent estimation of stature from the estimated maximum length.

All measured variables on the femur in chapter three showed a moderate to high positive correlation with stature (Table 3.3, page 71). The medial condyle length and bicondylar breadth showed the highest correlation in both males and females. In the male sample, the medial condyle length also showed the highest correlation with maximum length of the femur while the upper epicondylar length displayed the best correlation in the female sample. The obtained correlation coefficients in this chapter are higher than those presented by Simmons *et al.* (1990) for African Americans (Table 3.5, page 76). This indicates that the measured variables of the femur in this chapter have a higher predictive efficiency compared to those presented by Simmons *et al*. (1990).

Regression equations for estimation of skeletal height from measurements of femur are presented for the first time in South Africa in Table 3.3 (page 71). The range of standard error of estimate (SEE) for these equations in both sexes is higher than those presented for the intact femur by Lundy and Feldesman (1987), which indicates that the presented equations in this chapter have a lower predictive accuracy compared to those presented for intact femur; however, the range of the SEEs in chapter three are lower than that presented for measurements of the skull (Ryan and Bidmos, 2007), fragmentary tibiae (Chibba and Bidmos, 2007) and calcanei (Bidmos and Asala, 2005; Bidmos, 2006). Therefore, in the absences of intact femur, regression equations formulated in chapter three will provide a more reliable estimate of skeletal height compared with the skull, fragments of tibia and the calcaneus.

Even though some anthropologists (e.g. Pearson in 1899 as cited by Porter 2002; Trotter and Gleser, 1952a, 1958; Lundy, 1983a; Holland, 1995) cautioned that a regression equation should be limited to the population group from which it has been formulated from, others researchers (e.g. Mysorekar *et al*, 1980; Byers *et al*., 1989) have ignored this warning and have subsequently developed “universally” applicable equations. Chapter 4 tackled the issue of population specificity of regression equations by assessing the reliability of regression equations derived from skeletons of indigenous South Africans in chapter three on samples of skeletons of South Africans of European Descent.

An assessment of the reliability of the regression equations derived for ISA males in chapter three on a sample of skeleton of SAED males revealed that the estimated skeletal height (TSH_{Est}) of SAED males are significantly higher ($p \leq 0.05$) than the measured skeletal height (TSH_{Fully}) (Table 4.2, page 88). Contrary to the observation in the male group, notable differences between the compared parameters were not observed in the female group. But subsequent analysis of data using bivariate scatter plot revealed marked differences between the two parameters for cases at the upper limit of skeletal height (Figure 4.1, pages 90-91). When these cases were subjected to paired *t* tests, statistically significant differences were observed between TSH_{Fully} and TSH_{Est} which therefore suggest population specificity of regression equations derived in chapter three for ISA and the need for the derivation of new equations for SAED.

The range of obtained correlation between measurements of the femur and skeletal height for SAED in chapter four (0.525 – 0.782) is of similar magnitude compared to that presented in chapter three for ISA (0.523 – 0.816). This range of correlation is again higher than that presented for Americans (0.294 – 0.587) by Simmons *et al*. (1990). The accuracy of the equations in chapter four (SEE: 3.71 – 5.31) compares well with those (SEE: 3.72 – 4.38) in chapter three; however, this is lower than that presented for intact long bones of SAED by Dayal *et al*. (2008b).
In addition to regression equations for the direct estimation of skeletal height from measurements of the femur, chapters three and four also dealt with the formulation of regression equations for the estimation of maximum length of the femur from which skeletal height can be subsequently estimated. Moderate to high correlations were also obtained between maximum length of the femur and measurements of its fragments (Table 4.6, page 97). The range of SEE for the equations formulated for the estimation of maximum length of the femur in both chapters (1.33 – 2.11) is lower than those presented for the estimation of skeletal height (3.71 – 5.31). The question then arises as to which of the two methods, direct or indirect, provides a more accurate estimation of stature.

Steele (1970) concluded that the indirect method provides a more accurate estimate of stature compared to the direct method by using a hypothetical case as an illustration. In chapter 5, the issue of the accuracy of the two methods was investigated by using a larger sample of skeletons (N = 120). No statistically significant difference was observed between the estimated skeletal height (TSH_{Est}) from the use of the equations formulated for the direct estimation of skeletal height and the obtained skeletal height using Fully's method (TSH_{Fully}). The evaluation of the indirect method revealed a significant overestimation of TSH_{Fully} that indicates the direct method is more accurate than the indirect method. In addition, the SEE for each of the equations used in the indirect method of estimation after the necessary adjustment has been made is higher than that obtained for the direct method (Table 5.5, page 122), which is a further confirmation of the accuracy of the direct method. Since the direct method is also less complicated, it is therefore the preferred of the two methods.

As mentioned above and described in chapter two, it is a well established fact that intact long bones especially those of the lower extremities, in particular the femur and the tibia, have the best correlation with stature since they contribute directly to stature. It has also been established in chapters three and four that measurements of fragments of the femur have a moderate to high correlation with stature. The standard error of estimate of the regression equations derived from these measurements provide reasonable estimate of stature in South Africans.

Metatarsals are also classified as long bones like the femur and are sometimes available for forensic analysis. It remains one of the least studied bones in forensic anthropology and to date only one study has been conduced to assess its usefulness in stature reconstruction (Byers *et al*., 1989). Chapter six investigated the potential of six measurements of metatarsals in the estimation of skeletal height. How will regression equations derived from measurements of metatarsals compare with those of fragments of the femur and tibia?

8.3 Metatarsal lengths in stature reconstruction

Fully's technique (1956) was applied in the calculation of skeletal height for each of the 226 complete skeletons of South Africans that were selected in chapter six. In addition, six length measurements of the metatarsals were also taken. The correlation coefficient for all metatarsal measurements, except M4 for ISA male and $M5_P$ for both ISA male and female, showed moderate to high correlations with skeletal height. This result compares well with that of Byers *et al*. (1989) for Americans, but is better than that presented in chapters three and four for measurements of fragments of femur of South Africans.

The standard error of estimate for regression equations formulated from measurements of metatarsals (3.81 – 5.80) is lower than those obtained for the skull, fragments of tibia (5.2 – 6.7) and the calcaneus (4.0 – 5.9) which shows that metatarsals have a better predictive efficacy in stature estimation compared to these skeletal elements. Since SEE of regression equations derived for fragments of femur in chapters three and four is lower than that presented in chapter six, it is recommended that stature should be estimated from fragments of femur when they are available for forensic analysis. In their absence, regression equations formulated from measurements of metatarsals can also provide a reliable estimate of stature.

8.4 Issues arising from cadaver derived collections

Formulation of regression equations for the purpose of stature reconstruction requires the acquisition of two sets of data: the independent variable or stature and the dependent variable (e.g. length of long bones). Three kinds of measurements for stature are often encountered among the existing methods from cited studies in chapter two. These are: (i) living stature: this is the maximum stature of an individual measured in the living state. It is regarded as the primary data for stature and should be collected in an ideal case (e.g. Military personnel data in Trotter and Gleser, 1952, 1958 studies; Özaslan *et al.*, 2003); (ii) cadaver length: this has to be converted to living stature by subtracting 2 to 2.5cm, which is the magnitude of the lengthening of the cadaver after rigor mortis (e.g. Dupertuis and Hadden, 1951; De Medonça, 2000; Petrovečki *et al.*, 2007); and (iii) skeletal height: living stature is calculated from components of the skeleton as directed by Fully (1956) after which soft tissue correction indices are added to obtain an estimate of living stature (e.g. Lundy and Feldesman, 1989; Bidmos and Asala, 2005).

In South Africa, all studies on stature reconstruction so far have been based on the application of Fully's technique on skeletons obtained from the Raymond A. Dart and Pretoria Bone Collections. This method is not without limitations. Firstly, since it requires the presence of a complete skeleton, this limits the number of skeletons that can be used in the formulation of regression equations. Secondly, the reliability of the method was questioned by Bidmos (2005b) and led to the revision of the technique by Raxter *et al.* (2006). Thirdly, there was uncertainty regarding population specificity of soft tissue correction indices that were suggested by Fully (1956). This issue was dealt with in chapter seven and will be elucidated upon in the section below.

The application of the Fully’s technique has become necessary since documented cadaver lengths in the Raymond A. Dart and Pretoria Collections have been questioned (e.g. Lundy 1983a). Bidmos (2005b) noted some flaws in the technique used in the measurement of cadaver lengths that are documented in the catalogue of Raymond A. Dart Collection. Bidmos (2005b: 506) observed that “the plantar surfaces of the feet, for example, were not made to touch the footplate provided for that purpose. The soles of the feet were not at right angles to the body, while the neck was often in an extended position. The figures on the measuring tape attached to the measuring instrument used were not clear”. Bidmos (2005b) concluded that these factors may have added error to the final measurement and as a result these cadaveric lengths may not be entirely reliable, in support of the earlier observation made by Lundy (1983a). Are the other demographic information in the catalogue of the Raymond A. Dart Collection free of errors? Are the skeletons in the Dart Collection and other skeletal collections representative of the living population?

Komar and Grivas (2008) noted that cadaver derived skeletal collections were created from donation and autopsy in order to avoid certain problems that are inherent in archaeological populations. This notwithstanding, Komar and Grivas (2008) observed that the demographic information (e.g. age, sex, population affinity, cause of death) of individuals whose skeletons form the Maxwell Documented collection of New Mexico significantly differ from the living population. In addition, there is significant overrepresentation of males, Whites and the elderly which may result in biased sampling (Komar and Grivas, 2008). The issues of biased sampling and limitations of skeletal collections have also been discussed in other studies (Hunt and Albanese, 2005; L’Abbé *et al*. 2005; Dayal *et al*. 2009). Komar and Grivas (2008) however cautioned that even though documented skeletal collections are useful in the development of standards for human identification, these collections should not be considered as a proxy for modern populations.

Chapter seven was thus designed to avoid the limitations of the use of cadaveric derived materials as highlighted above. While it is possible to obtain measurements of the living heights from a sample of a living population, is it feasible to use MRI scans in the calculation of total skeletal height in order to assess the reliability of previously derived soft tissue correction indices on a sample of indigenous South Africans? What will be the challenges of this new technique and will these challenges supersede the benefits?

8.5 Role of MRI in stature reconstruction

The use of Fully's method (1956) in stature reconstruction requires that a soft tissue correction index should be added to skeletal height in order to obtain an estimate of living stature. Fully's (1956) soft tissue correction indices that were formulated for different ranges of skeletal height remain the most widely used for this purpose; however, recent studies (King, 2004; Bidmos, 2005b; Raxter *et al*. 2006) raised concerns about the reliability of Fully's soft tissue correction indices. This led to the revision of Fully's technique and the presentation of new "universally applicable" soft tissue correction indices by Raxter *et al*. (2006).

Chapter seven aimed to address the issue of the reliability of the soft tissue indices of Fully (1956) and Raxter *et al*. (2006). Apart from some of the limitations of the use of cadaveric derived materials as elucidated upon above, it was also thought that it would be more appropriate to assess the reliability of these soft tissue indices on a sample of the living population. The conduction of the study would therefore require the acquisition of radiographically determined measurements of bones. As mentioned in section 1.4 (page 13), MRI has numerous advantages over the conventional X-ray and CT scan and was thus selected for use in chapter seven.

The application of the MR imaging technique in stature reconstruction is very rare. Since no previous study in physical anthropology has been conducted with the dual application of Fully's method and MRI as shown in chapter seven, this is perhaps the most important contribution of this thesis to the field of forensic anthropology. The stadiometer was used in the measurements of the standing height of each subject. Fully's method was then used in the calculation of total skeletal height from full body MRI scan of each subject. Subsequent analyses of the acquired data revealed that the previously derived soft tissue correction indices of Fully (1956) and Raxter *et al*. (2006) are not applicable to the studied sample which necessitated the derivation of a new soft tissue correction index with an accuracy of 100% of statures estimated within 1 standard error of estimate; however, the application of this new technique as described in chapter seven was not without limitations. Despite this, these limitations did not significantly affect the outcome of the chapter and some of the results presented compare well with those from certain previous work on stature reconstruction in South Africa (e.g. Lundy and Feldesman, 1987; Steyn and Smith, 2007, Dayal *et al*. 2008b).

In conclusion, results from this thesis have shown that:

1. Measurements of fragments of the femur and lengths of metatarsals display moderate to strong correlation with skeletal height;
2. Regression equations derived from measurements of fragments of the femur are more reliable than those of metatarsals in the estimation of stature contrary to one of the hypotheses of this thesis;
3. The direct method of estimation of skeletal height is more accurate compared to

the indirect method; and

4. Previously derived soft tissue correction indices are not applicable to a sample of ISA males, necessitating the calculation of a new soft tissue correction index.

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Appendix One

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Abstract Intact long bones of the upper and lower extremities have been used in the derivation of regression equations for the estimation of stature in different population groups. These bones are sometimes presented to forensic anthropologists in different states of fragmentation thereby making the derived equations unusable. This has necessitated the need to assess the usefulness of measurements of fragments of long bones (e.g., femur) in the estimation of stature. While few studies have reported such equations, which are population and sex specific, it was the aim of this study to derive equations based on measurements of commonly preserved fragments of the femur for the indigenous South African population group. A total of 100 complete skeletons, equally distributed by sex, were obtained from the Raymond A. Dart collection of human skeletons. Stature was estimated for each of the skeleton using the Fully's method (Fully in Ann Med Leg 35:266–273, 1956). Regression equation for the estimation of stature and maximum length of the femur were derived from six measurements of the femur. The standard error of estimate for regression equations for stature estimation (3.72–4.38) was slightly higher than that presented for intact femur. This study confirms the usefulness of fragments of the femur of indigenous South Africans in the estimation of stature.

Keywords Stature · Fragmentary femur · South Africa · Forensic anthropology

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Introduction

The estimation of stature and body size is of great interest to forensic and physical anthropologists. A detailed account of the different methods of stature estimation and body size from bones using various techniques is well documented in previous studies by Lundy [1], Krogman and İşcan [2], and Porter [3]. In 1899, Pearson developed arguably the most used statistical theorems in stature reconstruction termed regression analysis [2]. This theory was used in the derivation of population and sex-specific regression equations for the estimation of stature [2, 3]. Subsequently, there has been a lot of interest to derive similar equations using intact long bones of the upper and lower limbs in Americans [4,5], British and East Africans [6], South Africans [7, 8, 9], Portuguese [10], Germans [11], Bulgarians [12], and Turks [13] among others. Attempts were also made to formulate regression equations using measurements of the skull [14, 15] and other postcranial elements [16–21]. From the results of all these studies, the femur in the intact state is one of the bones with the highest correlation with stature. It has also been shown to yield the best accuracy in the estimation of stature for any individual skeletal element [22].

However, the femur is not always recovered intact in forensic and archaeological cases thereby rendering the equations derived from the whole bone inappropriate for analysis. This has necessitated the derivation of regression equations from fragments of the femur. Steele and McKern [23] made the first attempt at estimating stature from fragments of the femur using five landmarks from which four segments were delineated. They [23] derived regression equations for the estimation of maximum length of the femur from each of the segments and combinations of these segments using prehistoric American femora obtained from three different sites in Mississippi. Similar equations were also presented for the estimation of maximum length of the humerus and tibia from different segments of these bones.

The method of estimating maximum length of the femur from its segments was revised by Simmons et al. [24] because the techniques for delineating segments of this bone as suggested by Steele and McKern [23] were not easily reproducible. Simmons et al. [24] used seven standard measurements of femur obtained from the Terry Collection in the derivation of equations for estimation of maximum length of femur and stature. Studies have also been conducted on the usefulness of fragments of the upper end of the radius and the lower end of the femur [25], segments of the ulna and tibia [26], and fragments of tibia [27, 28] in the estimation of stature with different degrees of success.

Because no studies have yet been conducted on the estimation of stature from fragments of the femur in South Africa, this study aimed to derive regression equations for estimation of the maximum length of the femur and stature from fragments of the femur.

Materials and methods

Materials

Two sets of samples were used in this study. The calibration sample (sample A) consisted of 100 (50 male and 50 female) complete skeletons of indigenous South Africans (ISAs). This sample was used in the derivation of regression equations for estimation of the maximum length of femur and stature. The test sample (sample B) of 20 complete skeletons, equally distributed by sex, was used in the assessment of the reliability of the derived regression equations. These skeletal elements were obtained from the Raymond A. Dart collection of human skeletons housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg, South Africa.

The ISA population group consisted of various tribes including Zulu, Xhosa, Tswana, Sotho, Pedi, Venda, etc, but for the purpose of this study, samples were obtained mainly from the Zulu, Xosa, Sotho, and Tswana tribes, as they constitute the majority of the skeletons of the ISA population group in the Raymond A. Dart Collection. These four chiefdoms were treated as a single homogeneous group because previous studies have shown that no statistically significant intertribal differences exist in the metrical analyses of skulls [29] and postcranial skeletons [1].

The ages of individuals whose skeletons form the samples used in this study ranged between 46 and 75 years. Period of death for these skeletons ranged between 1975 and 2000. Complete skeletons comprised of a complete skull, vertebrae, femur, tibia, talus, and calcaneus were used. Specimens with missing elements including calvaria, broken edges, and those with excessive osteophytic lippings were excluded from this study.

Methods

A simple random sampling technique was used in the selection of skeletal materials because it gives all specimens an equal opportunity of being chosen. Fully's [30] method was used in the calculation of total skeletal height (TSH). This became necessary, as previous studies have shown that documented cadaver lengths in the Raymond A. Dart Collection are not reliable [1, 31]. The following measurements as described by Fully [30] and Bräuer [32] were taken on each complete skeleton:

1. Basi-bregmatic height of the skull using a spreading caliper
2. Maximum heights of vertebrae (C2–S1) using a sliding caliper
3. Physiological length of the femur using an osteometric board
4. Lateral condylomalleolar length of the tibia using an osteometric board
5. Articulated height of the talus and calcaneus using an osteometric board

The sum total of these measurements gives an estimate of TSH. In addition to the abovementioned, seven other measurements were taken on each left femur. They are as described below following the instructions of Bräuer [33]:

1. Maximum length of femur: the linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle
2. Upper epicondylar length (UEpL) or upper breadth of femur (VHA): the linear measurement between the most superior point on the fovea capitis of the femur to the inferior aspect of the greater trochanter
3. Vertical neck diameter (VND): the minimum linear distance between the superior and inferior points on the neck of the femur
4. Epicondylar breadth (EpB): the linear distance between the medial border of the medial condyle and the lateral border of the lateral condyle
5. Bicondylar breadth (BCB): the linear distance between the medial and the lateral epicondyles of the femur
6. Medial condyle length (MCL): the linear distance between the most anterior and the most posterior points on the medial condyle
7. Lateral condyle length (LCL): the linear distance on the lateral condyle measured in an anteroposterior direction

Table 1 Descriptive statistics

	Males			Females			F statistic	p value
Measurements	Number	Mean	Standard deviation	Number	Mean	Standard deviation		
TSH	50	153.21	5.53	50	143.12	6.95	64.56	0.0000
MaxL	50	454.60	21.38	50	428.60	25.37	30.69	0.0000
BCB	50	78.72	4.05	50	69.96	5.04	91.79	0.0000
UEpL	50	95.32	5.96	50	85.74	6.59	58.16	0.0000
VND	50	32.31	2.44	50	28.20	2.52	68.65	0.0000
MCL	50	64.55	3.75	50	57.86	3.62	82.37	0.0000
LCL	50	64.73	3.58	50	59.86	4.41	36.75	0.0000
EpB	50	74.93	4.61	50	66.60	4.96	75.66	0.0000

All femoral measurements are in mm.
TSH Total skeletal height in cm, *MaxL* maximum length of femur, *BCB* bicondylar breadth, *UEpL* upper epicondylar length, *VND* vertical neck diameter, *MCL* medial condyle length, *LCL* lateral condyle length, *EpB* epicondylar breadth

The maximum length and BCB were measured on an osteometric board, while the rest of the measurements were taken using a vernier caliper.

Lin's [33] concordance coefficient of reproducibility was used in the assessment of the reliability of the measuring technique used in this study, and ten complete skeletons were used for this purpose. After establishing that the measuring technique was adequate, data were collected and placed into excel spreadsheets, and statistical analysis was carried out on the male and female groups separately using the "Statistix" program.

Descriptive statistics including means and standard deviations were obtained for both sexes. Normality of distribution of data for both sexes was also verified by comparing the histograms of each femoral measurement with the normal distribution curve. Thereafter, univariate and multivariate regression analyses were performed. Firstly, TSH was regressed on individual measurements and combinations of measurements of the femur. Secondly, the maximum length of the femur was regressed against individual measurements and combinations of measurements of the femur. From these analyses, the correlation coefficient (r), unstandardized coefficient, constant, and standard error of estimate (SEE) were obtained. Regression equations were formulated from these coefficients and constants.

Femoral measurements from each of the specimens in the test sample were substituted separately for males and females into appropriate regression equations derived in this study for estimation of (a) maximum length of the femur and (b) stature. To assess the reliability of each regression equation in the estimation of stature, the number of specimens with calculated TSH (using Fully's method) falling within 1 and 2 standard errors of estimation of the estimated skeletal height (using derived regression equation from the present study) is expressed as a percentage of the total number of specimens in the tested sample. A similar procedure was also performed for regression equations derived for estimation of maximum length of the femur.

Results

The means and standard deviations of femoral measurements and TSH are presented in Table 1. Males consistently showed significantly ($p<0.001$) higher mean values for all the measurements compared with females. The mean ages for males and females were 41.8 and 46.5 years, respectively.

All measurements of the femur showed a positive correlation with TSH. The MCL showed the highest correlation (0.74) with TSH (Table 2) in the male sample while the other measurements displayed moderate correlation with TSH (Table 2). However, all femoral dimensions in the female sample displayed high correlation with TSH (Table 2).

Table 3 shows equations that can be used in the estimation of TSH from measurements of the femur. The equations are arranged in increasing order of correlation and decreasing order of SEE. The range of correlation coefficient (0.62–0.76) for the equations in males is lower than that obtained for females (0.80–0.85), while the range of SEE in males (3.72–4.36) compares well with that obtained for females (3.82–4.18). The addition to and subtraction of SEE from the final estimate provides a range for TSH. As an illustration, a male individual with LCL of 60 mm will have a TSH of (see Eq. 1 in Table 3):

$$\begin{aligned} \text{TSH} &= [(0.96 \times 60) + 90.86] \pm 4.36\ \text{cm} \\ &= (57.6 + 90.86 \pm 4.36\ \text{cm}) \\ &= 148.46 \pm 4.36\ \text{cm} \end{aligned}$$

Table 2 Correlations of femoral measurements with stature and maximum length of femur

Measurements	Males		Females	
	TSH	MaxL	TSH	MaxL
BCB	0.559	0.529	0.816	0.720
UEpL	0.608	0.653	0.785	0.799
VND	0.542	0.517	0.731	0.681
MCL	0.744	0.711	0.735	0.619
LCL	0.623	0.626	0.769	0.696
EpB	0.523	0.560	0.803	0.746

BCB Bicondylar breadth, *UEpL* upper epicondylar length, *VND* vertical neck diameter, *MCL* medial condyle length, *LCL* lateral condyle length, *EpB* epicondylar breadth

Addition of a soft tissue factor of 10.0 cm for a skeletal height of less than or equal to 153.5 cm as suggested by Fully [30] gives a living stature estimate of:

$$\text{ELS} = 158.46 \pm 4.36$$

Therefore, the estimated living stature of the individual will range between 154.10 and 162.82 cm.

Males showed a moderate correlation between individual femoral variables and maximum length of the femur, while a higher degree of correlation was obtained in the female sample (Table 2). Regression equations that can be used in the estimation of maximum length of the femur from various combinations of femoral variables are presented in Table 4. Equations derived for female samples presented with a higher correlation (0.80–0.83) compared with that obtained for the male sample (0.63–0.75). The SEE obtained for the estimation of maximum length of the femur from its fragments ranged from 1.46 to 1.69 cm for males and 1.48 to 1.54 cm in females.

The result of the accuracy of derived regression equations for estimation of maximum length of the femur and TSH at 1 and 2 standard errors of estimate are shown in Tables 3 and 4. In general, a higher degree of accuracy was obtained in both sexes at 2 SEE.

Discussion

In an attempt to derive equations for stature estimation using fragments of femur, Simmons et al. [24] reported a difficulty in reproducing the measurements as suggested by Steele and McKern [23]. As a result, Simmons et al. [24] used eight standard measurements of the femur in the estimation of the stature of Americans. In the present study, four of the measurements were used because of the high coefficient of reproducibility that was obtained. These are: VND, VHA or UEpL, BCB, and EpB. In addition to these, two other measurements namely, medial and lateral condylar lengths, were selected because they have been shown to be sexually dimorphic in ISAs [34] and also because of their high coefficient of reproducibility.

Each of these six measurements showed statistically significant sex differences. This indicates that fragments of the femur are sexually dimorphic in this population group, which is in support of earlier observations made by Asala et al. [34]. A comparison of the mean measurements from the present study with those obtained by Asala et al. [34] showed no statistically significant difference. The result of this comparison can be explained based on the fact that the

Table 3 Equations for stature estimation (in cm), correlation, and standard error of estimate from fragments of femur

	Equations	Correlation	SEE	Accuracy(%)	
				1 SEE	2 SEE
Male					
1	0.96(LCL)+90.86	0.62	4.36	80.0	100.0
2	1.10(MCL)+82.47	0.74	3.73	70.0	100.0
3	0.93(MCL)+0.14(UEpL)+79.42	0.75	3.72	100.0	100.0
4	1.24(MCL)−0.17(BCB)+86.22	0.75	3.75	100.0	100.0
5	1.02(MCL)+0.19(UEpL)−0.16(EpB)+81.04	0.76	3.73	100.0	100.0
6	1.10(MCL)+0.16(UEpL)−0.21(BCB)+83.78	0.76	3.73	90.0	100.0
Female					
1	1.13(EpB)+68.19	0.80	4.18	70.0	100.0
2	1.13(BCB)+64.42	0.82	4.06	50.0	100.0
3	0.73(EpB)+0.59(LCL)+59.62	0.84	3.87	60.0	90.0
4	0.73(BCB)+0.36(UEpL)+61.08	0.84	3.88	60.0	100.0
5	0.55(EpB)+0.53(LCL)+0.53(VND)+59.62	0.85	3.82	70.0	100.0

Fully's soft tissue correction factors: TSH≤153.5 cm, add 10 cm; between 153.6 and 165.4 cm, add 10.5 cm; and ≥165.5 cm, add 11.5 cm
For example, a male with MCL of dimemsion 70 mm will give TSH=(1.10×70)+82.47=77+82.47=159.47 cm
Living stature will therefore be 159.47+10.5 cm±SEE=169.97 cm±3.73

Table 4 Equations for estimation of maximum length of femur (in mm), correlation, and standard error of estimate from fragments of femur

	Equations	Correlation	SEE	Accuracy(%)	
				1 SEE	2 SEE
Male					
1	0.37(LCL)+21.23	0.63	1.69	90.0	100.0
2	0.41(MCL)+19.32	0.71	1.52	70.0	100.0
3	0.47(MCL)−0.01(BCB)+20.88	0.72	1.53	70.0	100.0
4	0.29(MCL)+0.11(UEpL)+17.04	0.74	1.47	70.0	100.0
5	0.12(UEpL)+0.36(MCL)−0.10(BCB)+19.14	0.75	1.46	70.0	100.0
6	0.12(UEpL)−0.10(BCB)+0.37(MCL)−0.01(LCL)+19.21	0.75	1.48	70.0	100.0
Female					
1	0.31(UEpL)+16.46	0.80	1.54	80.0	90.0
2	0.24(UEpL)+0.11(EpB)+15.33	0.81	1.53	80.0	90.0
3	0.24(UEpL)+0.25(VND)+15.03	0.82	1.48	80.0	100.0
4	0.26(UEpL)−0.06(MCL)+0.28(VND)+16.14	0.82	1.49	80.0	100.0
5	0.23(UEpL)−0.17(MCL)+0.28(VND)+0.15(LCL)+16.70	0.83	1.48	80.0	100.0
6	0.04(EpB)+0.15(LCL)+0.26(VND)+0.21(UEpL)−0.19(MCL)+16.63	0.83	1.50	80.0	100.0

two studies used recently acquired skeletal materials from the same population group. The two studies differ in that Asala et al. [34] used a larger sample size and did not include the Tswana tribe.

All femoral measurements used in this study showed positive correlation with maximum length of the femur and stature (Table 2). Females consistently showed higher correlation coefficients compared to males. This is consistent with observations made from previous studies [20, 21, 28]. Because femoral measurements are small in dimension compared to stature, one would expect that the degree of correlation is lower compared to that for the maximum length of the femur. However, most measurements of the femur showed a higher degree of correlation for stature compared with the maximum length of the femur in both sexes (Table 2). This observation is not unusual and has been reported in earlier studies by Simmons et al. [24] and Chibba and Bidmos [28] using the femur and tibia, respectively, in which higher correlation coefficients were obtained between measurements of these bones and stature compared to that between the maximum length of these bones and measurements of their fragments.

Measurements of the distal end of the femur consistently showed the best correlation with stature and maximum length of the femur. In males, the medial and lateral condyle lengths showed the highest correlation with stature, while the BCB displayed the highest correlation in females (Table 2). However, the UEpL, one of the measurements on the proximal aspect of the femur, showed the highest correlation with the maximum length of the femur in females and also displayed the second best correlation in males (Table 2). The general trend in this study whereby measurements of the distal end of the femur displayed the highest correlation with stature and maximum length of femur differs from the observation made by Simmons et al. [24]. In the latter study [24], the UEpL, a proximal femora measurement, consistently showed the best correlation with stature and maximum length of femur in both sexes.

Table 5 shows the correlation coefficients of comparable measurements of the femur in the present study and those of Simmons et al. [24] with the maximum length of the femur and stature. For three out of the four measurements, the correlation reported in this study was higher than that of Simmons et al. [24] in males. However, all female measure-

Table 5 Comparison of correlation coefficients from Simmons et al. and the present study

	Male				Female			
	Simmons et al.		Present study		Simmons et al.		Present study	
	MaxL	Stature	MaxL	Stature	MaxL	Stature	MaxL	Stature
UEpL (VHA)	0.592	0.564	0.653	0.608	0.513	0.432	0.799	0.785
VND	0.315	0.393	0.517	0.542	0.422	0.461	0.681	0.731
BCB	0.440	0.509	0.529	0.559	0.345	0.220	0.720	0.816
EpB (FDL)	0.465	0.560	0.560	0.523	0.415	0.329	0.746	0.803

ments in this study showed a higher correlation compared with the corresponding measurements of Simmons et al. [24]. This indicates that the measured variables in this study have a higher predictive efficiency compared to those used by Simmons et al. [24]. The moderate to high correlations obtained in this study confirm the usefulness of fragments of femur of the ISA population group in the estimation of stature and maximum length of the femur. Regression equations derived from these measurements will therefore be of great assistance to forensic and physical anthropologists in South Africa in the estimation of stature.

Conclusions

Measurements of the proximal and distal ends of the femur of the ISA population group have been shown to be sexually dimorphic in a previous study by Asala et al. [34]. In the present study, these measurements showed a moderate to high positive correlation with stature. The MCL and BCB, both being distal end measurements, showed the highest correlation in both males and females. The MCL also showed the highest correlation with maximum length of femur in males, while UEpL, a proximal measurement, displayed the best correlation in the female sample. Correlation coefficients for comparable measurements in this study are higher than those presented by Simmons et al. [23] for African Americans, thereby showing a higher predictive efficiency of measurements used in this study. Regression equations for stature estimation and maximum length of femur using various combinations of measurements of the femur in both sexes are presented. The range of SEE for regression equations for estimation of stature in males and females is higher than that presented for intact femurs by Lundy and Feldesman [8] and lower than that obtained for intact metatarsals [16], metacarpals [17], calcanei [20, 21], and fragmentary tibiae [27, 28]. In the absence of intact femur, therefore, regression equations derived in this study are more reliable in the estimation of stature compared with the aforementioned skeletal elements i.e., metatarsals, metacarpals, calcanei, and fragmentary tibiae.

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Appendix Two

Bidmos MA 2008 Stature reconstruction using fragmentary femora in South Africans of European descent. *Journal of Forensic Sciences*. 53 (5): 1044-1048

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TECHNICAL NOTE

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Stature Reconstruction Using Fragmentary Femora in South Africans of European Descent

ABSTRACT: It is well documented that the intact femur has the highest correlation with stature and as such has been widely used in the derivation of regression equations for stature estimation. As intact femur is not always present for analyses in forensic cases, it has become necessary to derive regression equations for the estimation of stature from fragments of this bone. Few studies have presented regression equations for stature estimation from fragments of the femur. Because these equations are population specific, it was the aim of this study to derive similar equations for estimation of stature and maximum length of femur from measurements of the femur of South Africans of European descent. A sample of 50 male and 50 female complete skeletons were obtained from the Raymond A. Dart Collection of Human Skeletons. Total skeletal height for each of the skeletons was calculated using the Fully's method. Six variables were measured on each femur which included the vertical neck diameter, upper breadth of femur, epicondylar breadth, bicondylar breadth, lateral condyle length, and medial condyle length. Regression equations for the estimation of stature are presented. The range of standard error of estimate for these equations (3.71–5.31) was slightly higher than those obtained for intact long bones (2.13–3.79). It is therefore suggested that in the absence of intact femur, regression equations derived from the present study can provide a reliable estimate of adult stature.

KEYWORDS: forensic science, stature, fragmentary femur, South Africa, forensic anthropology

There has been a lot of interest in the estimation of stature from different elements of the human skeleton since the 19th century when Pearson first derived regression equations for stature estimation (1). This method of stature estimation is based on the relationship between lengths of long bones and stature and is often referred to as the mathematical method (2). The other method of stature estimation involves the use of the entire skeleton by summing up appropriate measurements from the skull to the foot (2). This method was first suggested by Fully (3) and is sometimes called the anatomical method. The advantages and disadvantages of these methods have been discussed in a previous study (2).

Most studies conducted on stature estimation using the mathematical method revolve around the use of intact long bones of the upper and lower extremities (4–13). Measurements of the skull (14,15) and postcranial elements (16–21) have also been used in the formulation of regression equations for stature estimation. These equations are population and sex specific. The femur has been shown to be the most useful because it has the highest correlation with stature (1,22). Unfortunately, the femur is sometimes found in different states of fragmentation which therefore renders the equations derived from the intact bone inappropriate especially in forensic cases. This has necessitated the derivation of regression equations from fragments of the femur.

Steele and McKern (23) conducted one of the earliest studies on stature estimation from fragments of long bones. They identified landmarks on the humerus, femur, and tibia of Americans from which these bones were divided into segments (23). The percentage proportion of each segment to the maximum length of the long bone was then calculated. Stature was subsequently estimated from the calculated maximum length of the long bone using previously derived appropriate regression equations (23). Similar studies were carried out in India by Mysorekar et al. (24,25). In 1990, Simmons et al. (26) suggested the use of standard measurements of the femur in the estimation of stature and maximum length of femur (MAXL) because of the difficulty in easily reproducing measurements of segments of the femur as suggested by Steele and McKern (23). Subsequently, standard tibial measurements were used for stature estimation in Americans (27), Guatemalans (28), and South Africans of European descent (29) with different degrees of success. As no previous study has been conducted on the usefulness of femoral measurements in stature estimation in South Africans of European descent, it is the aim of this study to derive regression equations for estimation of stature and maximum length of the femur (MAXL) in this population group.

Materials and Methods

The samples used in this study were obtained from the Raymond A. Dart Collection of Human Skeletons housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg, South Africa. The sample consisted of 50 male and 50 female complete skeletons of South Africans of European descent. These skeletal remains represent an admixture of individuals who are descendants of migrants from the Netherlands, the U.K., France, Germany, and other European countries (30). The following inclusion criteria were used in the selection of skeletons for this study: (i) presence of all skeletal elements that constitute stature; (ii) documented ages at death which ranged between 29 and 75 years; and (iii) absence of pathologies and excessive osteophytic lipping. These skeletons belong to individuals that died between 1957 and 1998.

Skeletons were selected using the simple random sampling technique. For each selected skeleton, total skeletal height (TSH) was

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TABLE 1—*Definition of measurements.*

Measurements	Abbreviation	Definition
Maximum length of femur	MAXL	The linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle.
Upper epicondylar length	UEpL	The linear measurement between the most superior point on the fovea capitis of the femur and the inferior aspect of the greater trochanter.
Vertical neck diameter	VND	The minimum linear distance between the superior and inferior points on the neck of the femur.
Epicondylar breadth	EpB	The linear distance between the medial border of the medial condyle and the lateral border of the lateral condyle.
Bicondylar breadth	BCB	The linear distance between the medial and the lateral epicondyles of the femur.
Medial condylar length	MCL	The linear distance between the most anterior and the most posterior points on the medial condyle.
Lateral condylar length	LCL	The linear distance on the lateral condyle measured in an anteroposterior direction.

estimated using the Fully's method (3). These measurements included: (i) basi-bregmatic height of the skull; (ii) maximum heights of vertebrae (C2-S1); (iii) physiological length of the femur, (iv) lateral condylomalleolar length of the tibia; and (v) articulated height of the talus and calcaneus.

In addition, seven measurements as described by Bräuer (31) were taken on each left femur (Table 1). All femoral measurements were taken using a vernier caliper except MAXL and bicondylar breadth which were measured on an osteometric board. Statistical analyses were carried out on each group (male and female) separately using the 'STATISTIX' program (32). Means and standard deviations for TSH and all femoral measurements were obtained for each group. Regression analyses were then performed in stages. First, TSH was regressed on individual and various combinations of measurements of the femur. Second, MAXL was also regressed against each of the six femoral measurements. From these analyses, the correlation coefficient (r), standard error of estimate (SEE), regression coefficient, and constant were obtained. Regression equations were formulated from coefficients and constants.

Results

Mean ages were 58 and 62 years for males and females, respectively. Males presented with statistically significant higher mean values compared to females with regard to TSH and all measurements of the femur (Table 2). The degree of association (correlation) between measurements of segments of the femur, MAXL and TSH are presented in Table 3. Generally, a moderate-to-strong correlation was observed.

In males, all measured variables on the femur showed significant positive correlation with TSH. Upper epicondylar length (0.661) displayed the highest correlation with TSH for an individual measurement while epicondylar breadth (0.525) showed the lowest correlation. A lower degree of correlation was obtained between MAXL and femoral measurements. This ranged between 0.400 for epicondylar breadth and 0.610 for upper epicondylar length (Table 3). In females, a strong positive correlation was observed between measurements of the femur and stature. Lateral condyle length (0.785) presented with the highest correlation while vertical neck diameter and upper epicondylar length (0.562) showed the least correlation (Table 3). A similar pattern of correlation was obtained between MAXL and its measurements (Table 3).

Table 4 shows regression equations that can be used in the estimation of stature from femoral measurements. These equations are arranged in descending order of SEE and increasing order of correlation. Only the best equations with reasonable application are presented. In males, functions 1 and 2 were derived from the lateral condyle length and upper epicondylar length because they both showed the highest correlation for an individual measurement (Table 4). The other functions, formed from various combinations of measurements of femur, presented with lower SEE (4.80–4.89) and higher correlation coefficient (0.73–0.75). Regression equations for females are also presented in Table 4. The highest correlation for an individual measurement was obtained for bicondylar breadth and lateral condylar length. The degree of correlation between TSH and different combinations of measurements ranged from 0.82 to 0.83. Equations for predicting TSH in females (Table 4) also presented with better accuracy as shown from the range of SEE (3.71–3.95).

In the estimation of MAXL from measurements of its parts, regression equations for males showed moderate correlation between femoral measurements and MAXL (Table 5). In the female sample, moderate-to-high correlation was obtained. This ranged between 0.78 and 0.83 (Table 5). The SEE obtained for

TABLE 2—*Descriptive statistics.*

	Males			Females				
Measurements	n	Mean	SD	n	Mean	SD	F statistic	p-value
TSH/cm	50	157.44	6.99	50	147.60	6.28	54.76	0.000
MAXL	50	465.22	27.56	50	433.80	22.18	39.43	0.000
BCB	50	80.68	4.18	50	72.22	3.91	109.22	0.000
UEpL	50	99.90	5.63	50	90.12	5.56	76.29	0.000
VND	49	33.99	2.70	50	29.92	2.77	54.76	0.000
MCL	50	65.33	3.70	50	59.54	3.19	70.32	0.000
LCL	50	65.18	3.53	50	60.30	3.47	48.61	0.000
EpB	48	75.99	3.35	44	67.37	4.11	122.21	0.000

TSH, total skeletal height; MAXL, maximum length of femur; BCB, bicondylar breadth; UEpL, upper epicondylar length; VND, vertical neck diameter; MCL, medial condyle length; LCL, lateral condyle length; EpB, epicondylar breadth.

TABLE 3—*Correlations of measurements of fragments of femur with maximum length of femur and stature.*

	Males		Females	
Variable	TSH	MAXL	TSH	MAXL
BCB	0.609	0.459	0.782	0.781
UEpL	0.661	0.610	0.562	0.623
VND	0.585	0.478	0.562	0.544
MCL	0.582	0.426	0.729	0.724
LCL	0.659	0.537	0.785	0.753
EpB	0.525	0.400	0.705	0.722

BCB, bicondylar breadth; UEpL, upper epicondylar length; VND, vertical neck diameter; MCL, medial condyle length; LCL, lateral condyle length; EpB, epicondylar breadth.

TABLE 4—*Equations for stature estimation (cm), correlation, and standard error of estimate (SEE) from fragments of femur.*

	Equations	Correlation	SEE
	Male		
1	1.31(LCL) + 72.32	0.66	5.31
2	0.82(UEpL) + 75.64	0.66	5.31
3	0.50(UEpL) + 0.80(LCL) + 55.63	0.73	4.89
4	0.53(UEpL) + 0.58(VND) + 0.58(LCL) − 0.22(EpB) + 63.68	0.74	4.81
5	0.49(UEpL) + 0.54(VND) + 0.53(LCL) + 55.93	0.75	4.80
6	0.55(UEpL) + 0.56(VND) + 0.41(LCL) + 0.41(BCB) − 0.49(EpB) + 61.07	0.75	4.80
	Female		
1	1.26(BCB) + 56.96	0.78	3.95
2	1.42(LCL) + 61.88	0.78	3.93
3	1.21(LCL) + 0.38(EpB) + 48.83	0.82	3.78
4	0.67(BCB) + 0.79(LCL) + 52.00	0.82	3.71
5	0.37(BCB) + 1.03(LCL) + 0.17(EpB) + 47.07	0.83	3.78
6	0.40(BCB) − 0.21(VND) + 1.07(LCL) + 0.23(EpB) + 45.43	0.83	3.81

TABLE 5—*Equations for estimation of maximum length of femur (cm), correlation, and standard error of estimate (SEE) from fragments of femur.*

	Equations	Correlation	SEE
	Male		
1	0.30(UEpL) + 16.73	0.61	2.21
2	0.25(UEpL) + 0.21(VND) − 0.06(EpB) + 18.31	0.62	2.17
3	0.23(UEpL) − 0.04(BCB) + 0.22(VND) − 0.16(MCL) + 0.24(LCL) − 0.05(EpB) + 17.81	0.64	2.21
4	0.22(UEpL) + 0.16(VND) − 0.01(BCB) + 0.13(LCL) + 12.61	0.65	2.20
5	0.25(UEpL) + 0.21(VND) + 14.20	0.65	2.17
6	0.22(UEpL) + 0.19(VND) + 0.02(BCB) + 0.24(LCL) − 0.19(MCL) + 12.73	0.66	2.19
	Female		
1	0.44(BCB) + 11.42	0.78	1.40
2	0.33(BCB) + 0.11(UEpL) + 9.95	0.80	1.36
3	0.29(BCB) + 0.21(LCL) + 10.10	0.80	1.36
4	0.22(BCB) + 0.09(UEpL) + 0.17(LCL) + 9.14	0.81	1.33
5	0.26(BCB) + 0.11(UEpL) − 0.14(VND) + 0.18(LCL) + 7.81	0.82	1.33
6	0.22(BCB) + 0.11(UEpL) − 0.14(VND) + 0.20(LCL) + 0.06(EpB) + 6.26	0.83	1.37

maximum femoral length estimation from its fragments ranged from 2.17–2.21 cm for males and 1.33–1.40 cm in females.

Discussion

The results of the descriptive statistics showed that males presented with statistically significant higher mean value of TSH than females (Table 2). It can therefore be inferred that males are generally taller than females which is in support of previous studies on stature estimation in South Africa (6,7,15,20,21,29). Males also showed higher mean values compared to females for all femoral measurements thereby confirming sexual dimorphism of femoral dimensions as reported in an earlier study by Steyn and İşcan (30).

According to Steele and McKern (23), Müller made the first attempt in estimating the maximum length of a long bone from measurements of its sections. Müller divided the humerus, radius, and tibia into sections from which percentage contribution of each section to the maximum length of the long bone was obtained (23). Steele and McKern (23) criticized the exclusion of femur from Müller's selection because the femur is regarded as the singular bone with one of the highest correlations with stature. They (23) replaced the radius with the femur in their study but used the method of delineating a long bone into sections as suggested by Müller.

In an attempt to derive equations for stature estimation using fragments of femur from a sample of a more recent skeletal collection, Simmons et al. (26) reported a difficulty in reproducing the measurements as suggested by Steele and McKern (23). As a result, Simmons et al. (26) used eight standard measurements of the femur namely: (i) vertical diameter of femoral head; (ii) vertical diameter of femoral neck; (iii) upper breadth of femur; (iv) transverse diameter of midshaft; (v) bicondylar breadth; (vi) epicondylar breadth; (vii) lateral condylar height; and (viii) medial condylar height, in the estimation of stature of Americans. Four of the above mentioned measurements were used in the present study because of the ease with which they could be reproduced. In addition to these, two other measurements namely medial and lateral condylar lengths were selected because of their high coefficient of reproducibility.

All measurements used in this study showed positive correlation with MAXL and stature (Tables 4 and 5). Females consistently showed higher correlation coefficients compared to males which is in support of previous studies (e.g., 6, 7, 20, 21, 29). This could be caused by less variability in females compared to males as shown in the value of standard deviation for TSH and most femoral measurements. The range of correlation between femoral measurements and TSH in males (0.66–0.75) is slightly lower than that obtained for the female sample (0.78–0.83). This result is expected as measurements of fragments of the femur are small in dimension as compared with TSH. Therefore, the degree of correlation between these fragments and TSH in general should be moderate.

Measurements of the distal end of the femur consistently showed the best correlation with stature and MAXL in females (Tables 4 and 5). However, the upper epicondylar length, one of the measurements on the proximal aspect of the femur, showed the highest correlation with MAXL and stature in males (Tables 4 and 5). The lateral condylar length showed the second highest correlation for stature and MAXL in males. In general, measurements of the distal end of the femur displayed the highest correlation with stature and MAXL in this study which is contrary to the observation made by Simmons et al. (26). In the latter study (26), the upper epicondylar length, a proximal femora measurement consistently showed the best correlation with stature and MAXL in both sexes.

The correlation coefficients of comparable measurements of femur in the present study and those of Simmons et al. (26) with MAXL and stature are presented in Table 6. The general trend reveals that measurements in this study showed a higher correlation compared with corresponding measurements of Simmons et al. (26) in both sexes indicating that measurements in this study have a higher predictive efficiency compared to those used by Simmons et al. (26). The moderate-to-high degree of correlations obtained in the present study confirms the usefulness of fragments of femur in the estimation of stature in South Africans of European descent. Practitioners of forensic anthropology in South Africa will therefore find the regression equations presented in this study useful when intact long bones are not present for analysis.

The accuracy of each regression equation derived in this study was assessed using the obtained SEE. Regression equations for stature estimation in males presented with slightly higher SEE compared to those obtained for females (Table 4). Similar results were obtained for range of SEE for regression equations for estimation of MAXL from its fragments (Table 5). While this is in support of previous observation made by Chibba and Bidmos (29), it contradicts that made by Simmons et al. (26) whereby similar range of SEE were obtained for both sexes.

Table 7 shows a comparison of the range of SEE from some selected previous studies with that from the present study. The range of SEE from the present study is lower than that obtained for intact calcanei, metatarsals, metacarpals, and fragmentary tibiae. This suggests that regression equations derived from the present study using fragments of femur are more accurate in the estimation of stature compared to those derived in earlier studies using the calcaneus, metatarsals, metacarpals, and fragments of long bones of the lower extremity.

Conclusion

Regression equations were derived for estimation of stature and MAXL from measurements of fragments of the femur. Females showed higher correlation between measured variables and both stature and MAXL compared to males. This allowed for formulation of more accurate regression equations for females compared to males. The accuracy of the equations in this study is lower than that obtained for intact long bones but higher than that for other skeletal elements like metatarsals, metacarpals, intact calcaneus, and fragments of tibia. Therefore, intact long bones should be used in the estimation of stature when they are available for forensic analysis. However, in the absence of intact long bones, equations presented in this study can offer a reasonable estimate of stature.

TABLE 6—*Comparison of correlation coeffcients from Simmons et al. (26) and present study.*

	Male				Female			
	Simmons et al. (26)		Present Study		Simmons et al. (26)		Present Study	
	MAXL	Stature	MAXL	Stature	MAXL	Stature	MAXL	Stature
UEpL (VHA)	0.606	0.587	0.610	0.661	0.632	0.526	0.623	0.562
VND	0.384	0.312	0.478	0.585	0.409	0.409	0.544	0.562
BCB	0.541	0.512	0.459	0.609	0.445	0.294	0.781	0.782
EpB (FDL)	0.521	0.493	0.400	0.525	0.537	0.428	0.722	0.705

UEpL, upper epicondylar length; VND, vertical neck diameter; BCB, bicondylar breadth; EpB, epicondylar breadth.

TABLE 7 —*Comparison of standard errors of estimate for stature by different authors.*

Investigator	Skeletal Elements	SEE
Lundy and Feldesman (6)	Long bones of upper and lower limbs	1.8–5.3
Dayal (7)	Long bones of upper and lower limbs	1.8–5.5
Trotter and Gleser (4)	Long bones of upper and lower limbs	3.0–5.1
Present study	Fragments of femur	3.7–5.3
Bidmos and Asala (20)	Calcaneus	4.0–5.9
Holland (18)	Calcaneus	4.1–6.3
Bidmos (21)	Calcaneus	4.2–5.4
Byers et al. (16)	Metatarsals	4.0–7.6
Meadows and Jantz (17)	Metacarpals	5.1–5.7
Chibba and Bidmos (29)	Fragments of tibia	5.2–6.7
Simmons et al. (26)	Fragments of femur	5.5–7.2

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Appendix Three

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Forensic Anthropology Population Data

Fragmentary femora: Evaluation of the accuracy of the direct and indirect methods in stature reconstruction

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ABSTRACT

Selected measurements of the femur have been used in the derivation of regression equations for stature estimation in several populations. Various studies have indicated that stature can be estimated from fragmentary bones by either the direct or the indirect method. The direct method allows for the estimation of stature directly from individual or combination of measurements of fragments of the femur. However, the indirect method consists of two steps. An initial step which involves the estimation of maximum length of the femur from measurements of its fragments is followed by stature estimation from the estimated maximum length of the femur. While Steele noted that the indirect method provides a relatively more precise estimate of stature, none of the subsequent studies on stature reconstruction has addressed the issue of accuracy of the two methods. The current study utilized 120 complete skeletons obtained from the Raymond A. Dart Collection of Human Skeletons. Total skeletal height for each of the skeletons (TSH_{Fully}) was calculated using the Fully's method. Measurements of fragments of the femur acquired from the current study were substituted into each of the previously derived equations for Indigenous South Africans (ISA) and South Africans of European Descent (SAED) in order to obtain an estimate of the skeletal height (TSH_{Est}). Analyses were carried out separately for each group. An assessment of the differences between the estimated skeletal height (TSH_{Est}) and the obtained skeletal height using the Fully's method (TSH_{Fully}) was performed using the paired *t* test. While no significant difference was observed between TSH_{Fully} and TSH_{Est} for all equations (except one) used in the direct estimation of skeletal height, a number of indirect equations significantly overestimated TSH_{Fully}. These observations indicate that the direct method is more accurate than the indirect method. Since it is also less complicated, it is therefore the preferred of the two methods contrary to earlier recommendation made by Steele.

1. Introduction

Steele and McKern [1] conducted one of the earliest studies on stature reconstruction from fragments of long bones. They identified landmarks on the humerus, femur and tibia of prehistoric Americans and thereafter divided these bones into segments based on the identified landmarks. The percentage proportion of each segment to the maximum length of the long bone was then calculated. Regression equations were also presented for the estimation of stature and maximum length of these bones. In 1970, Steele [2] conducted a similar study using the same technique and skeletal elements (i.e. humerus, femur and tibia). However, his sample consisted of modern American population groups of European and African descent obtained from the Terry Collection housed in the Smithsonian National Museum of Natural History. He derived regression formulae for the estimation of maximum length of these bones from measurements of their segments [2]. An estimate of the living stature can be obtained by using a two-step approach. The initial step involves the estimation of maximum length of the specific long bone from measurements of its fragments. Thereafter, the estimated maximum length of the long bone can be substituted into the appropriate equation of Trotter and Gleser [3]. This is referred to as the indirect method of stature estimation from fragments of long bones.

The direct method allows for the estimation of stature directly from individual or combinations of measurements of fragments of long bones. Steele [2] presented such equations and attempted to compare the accuracy of the two methods. He concluded that the indirect approach should yield a more accurate estimate of stature but failed to give any detailed account of how he arrived at the conclusion. In 1990, Simmons et al. revised [4] Steele's method [2] by suggesting the use of standard measurements of the femur.

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While they presented regression equations for the estimation of maximum length of the femur and stature from three of the eight studied variables, they made no attempt to discuss the issue of the accuracy of the indirect method over the direct method as suggested by Steele [2]. Subsequent studies on stature reconstruction from fragmentary femora in Indigenous South Africans (ISA) [5] and South Africans of European Descent (SAED) [6] did not address this issue as well. It is therefore the aim of this study to investigate the accuracy of these two methods of stature reconstruction from measurements of fragments of the femur.

2. Materials and methods

The samples used in this study were obtained from the Raymond A. Dart Collection of Human Skeletons housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg, South Africa. The sample consisted of 120 complete skeletons of South Africans equally distributed by sex and population group. The Indigenous South Africans (ISA) and South Africans of European Descent (SAED) groups were selected for this study because they are the two largest population groups that are represented in the Raymond A. Dart Collection. The different tribes that constitute the ISA population group were treated as a single homogeneous group because previous studies have shown the non-existence of intertribal differences in their osteometric dimensions [7,8]. The SAED population group, on the other hand, consists of migrants mainly from the Netherlands, Britain, France and other European countries [9–11]. Steyn and İşcan observed that their osteometric characteristics are different from Europeans and American whites [9–11].

Skeletons were selected using the simple random sampling technique. For each selected skeleton, total skeletal height (TSH_{Fully}) was calculated using the Fully's method [12]. For this purpose, the following measurements as described by Fully [12] were taken on each complete skeleton:

(i) basi-bregmatic height of the skull using a spreading caliper;
(ii) maximum heights of vertebrae (C2-S1) using a sliding caliper;
(iii) physiological length of the femur using an osteometric board;
(iv) lateral condylomalleolar length of the tibia using an osteometric board; and
(v) articulated height of the talus and calcaneus using an osteometric board.

The sum total of these measurements gives an estimate of the total skeletal height (TSH_{Fully}).

In addition to the abovementioned, seven other measurements were taken on each left femur. They are as described below following the instructions of Bräuer [13]:

(i) maximum length of femur (MaxL): the linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle;
(ii) upper epicondylar length (UEpL) or upper breadth of femur (VHA): the linear measurement between the most superior point on the fovea capitis of the femur to the inferior aspect of the greater trochanter;
(iii) vertical neck diameter (VND): the minimum linear distance between the superior and inferior points on the neck of the femur;
(iv) epicondylar breadth (EpB): the linear distance between the medial border of the medial condyle and the lateral border of the lateral condyle;
(v) bicondylar breadth (BCB): the linear distance between the medial and the lateral epicondyles of the femur;
(vi) medial condyle length (MCL): the linear distance between the most anterior and the most posterior points on the medial condyle; and
(vii) lateral condyle length (LCL): the linear distance on the lateral condyle measured in an anteroposterior direction.

The maximum length and bicondylar breadth were measured on an osteometric board while the rest of the measurements were taken using a vernier caliper.

Statistical analyses were carried out on each of the four groups separately using the 'Statistix' program [14]. Means and standard deviations for skeletal height using Fully's method (TSH_{Fully}) and all femoral measurements were obtained for each group. Since regression equations for estimation of skeletal height using maximum length of the femur were not presented in previous studies on South Africans [15,16] such equations were derived in the current study. This became necessary as previous studies on stature reconstruction from fragments of long bones [1,2,4] utilized the maximum length and not the bicondylar length of the femur. This will allow for reasonable comparisons to be made between previous studies and the current study.

In assessing the accuracy of the direct method, the obtained dimensions from the current study were substituted into each of the previously derived equations for ISA [5] and SAED [6] in order to obtain an estimate of the skeletal height (TSH_{Est}). Analyses were carried out separately for each group. An assessment of the differences between the estimated skeletal height (TSH_{Est}) and the obtained skeletal height using the Fully's method (TSH_{Fully}) was performed using the paired t test. Mean of the differences, p-value and correlation between TSH_{Fully} and TSH_{Est} were calculated.

The indirect method consisted of two steps. Step one involved the calculation of the maximum length of the femur using the appropriate equations previously derived for ISA [5] and SAED [6]. Thereafter, TSH_{Est} was calculated by substituting the obtained maximum length into appropriate regression equations derived in this study. The mean of the difference between the calculated TSH_{Est} and TSH_{Fully} was thereafter calculated. The paired t test was used to assess whether statistically significant differences exist between these two parameters. The correlation between them was also calculated for each equation.

3. Results

Descriptive statistics for each of the four groups are presented in Table 1. SAED males presented with the highest values for all measurements followed by ISA males. The ISA female group displayed the smallest measurements. Due to the notable differences in the dimensions of the measured variables and in consonance with the advice of previous anthropologists concerning population and sex specificity of regression equations [17–21], new regression equations for the estimation of skeletal height from maximum length of the femur were derived (Table 2). A significantly strong positive correlation was shown between maximum length of femur and skeletal height (TSH_{Fully}) for all groups. The ISA female group presented with the best correlation (0.932) while their male counterparts presented with the least correlation (0.832). The range of the obtained standard error of estimate for these equations (2.55 for ISA female to 3.06 for ISA males) is also low, indicating a high accuracy of the presented regression equations.

Table 1
Descriptive statistics of skeletal height and measurements of the femur in South Africans.

Measurements	ISA males			ISA females			SAED males			SAED females		
	N	Mean	Std. dev.	N	Mean	Std. dev	N	Mean	Std. dev	N	Mean	Std. dev
TSH_F	30	153.38	5.03	30	140.38	5.93	30	157.50	6.46	30	146.13	6.31
MaxL	30	460.60	19.70	30	419.27	21.61	30	466.10	24.04	30	427.67	22.99
BCB	30	79.70	4.06	30	68.17	4.86	30	81.43	4.64	30	71.80	3.35
UEpL	30	95.37	4.89	30	84.45	6.03	30	99.58	6.09	30	89.89	4.78
VND	30	33.31	2.11	30	27.18	2.41	30	34.54	2.53	30	29.37	2.42
MCL	30	65.10	3.25	30	56.53	3.86	30	64.42	4.44	30	59.45	2.68
LCL	30	65.40	3.57	30	58.20	4.21	30	65.07	3.98	30	59.81	2.87
EpB	30	75.79	4.10	30	65.18	4.67	30	76.13	4.28	30	66.26	3.03

TSH_F = total skeletal height using Fully's method (in cm), N = sample size.
All femoral measurements are in mm: MaxL = maximum length of femur, BCB = bicondylar breadth, UEpL = upper epicondylar length, VND = vertical neck diameter, MCL = medial condyle length, LCL = lateral condyle length, EpB = epicondylar breadth.
ISA = Indigenous South African, SAED = South Africans of European Descent.

Table 2
Regression equations for the estimation of skeletal height from maximum length of femur.

Equations	SEE	R
ISA male		
0.22(MaxL) + 55.50	3.06	0.832
ISA female		
0.26(MaxL) + 33.74	2.55	0.932
SAED male		
0.23(MaxL) + 49.44	2.85	0.915
SAED female		
0.26(MaxL) + 36.07	2.66	0.906

MaxL = maximum length of femur.

Table 3 shows the mean of the difference between the obtained skeletal heights using Fully's method (TSH_{Fully}) and the estimated skeletal height from appropriate regression equations (derived for the direct estimation of skeletal height) of ISA and SAED. The mean difference between TSH_{Fully} and TSH_{Est} for all equations (except Eq. (7)) is minimal and statistically insignificant ($p \leq 0.05$). The overestimation of TSH_{Fully} by these equations (except Eq. (7)) is as low as 0.01 cm (Eq. (4), ISA male group; Eq. (14), SAED male) while the highest difference (1.3 cm) was observed for Eq. (18) in the SAED female population group. Eq. (3) of ISA male underestimated TSH_{Fully} by 0.1 cm and again this difference is not statistically significant. Of the 23 equations derived for the direct estimation of skeletal height, only one (Eq. (7)) showed a statistically significant difference between the compared skeletal heights. This equation overestimated TSH_{Fully} by 1.4 cm.

There is a general overestimation of TSH_{Fully} using the indirect method of stature estimation. The difference between TSH_{Fully} and TSH_{Est} in the ISA male group is statistically significant for all equations and ranged from 1.6 cm (Eq. (1), Table 4) to 3.7 cm (Eq. (4), Table 4). Three (Eqs. (7), (8) and (11), Table 4) of the six equations in the ISA female group produced statistically significant overestimations of $TSH_{Fully.}$ A similar observation compared to the ISA female was made in the SAED female group whereby three (Eqs. (20), (21) and (24), Table 4) equations also produced significant overestimation of TSH_{Fully}. However, only one equation for SAED males (Eq. (16), Table 4) showed significant difference between the skeletal heights in comparison.

A general trend of moderate to strong positive correlation was shown for all groups for both direct and indirect methods. In the direct estimation of skeletal height, the least correlation (0.58) was shown by Eq. (1) (Table 3) while Eq. (10) (Table 3) showed the highest correlation (0.79). A similar result was obtained for the correlation between skeletal heights for equations derived for the indirect estimation of skeletal height. This ranged between 0.58 for Eq. (1) (Table 4) and 0.79 for Eq. (12) (Table 4).

4. Discussion

The estimation of stature from fragments of long bones (e.g. the femur) can be carried out by using direct or indirect methods. The former involves the direct estimation of skeletal height from the measurements of fragments of the femur while the latter consists of two steps, an initial estimation of the maximum length of the femur, which is followed, by the estimation of stature from the estimated maximum length. Steele [2] observed that the two methods yielded different stature estimates in a hypothetical case he used as an illustration. He noted that "...the differences in stature estimates by the two methods to be greatest in White males, least in White females, and intermediate in Negro females and Negro males, in that order" [2, p. 91]. He argued that the lack of agreement of the estimates from the two different methods could be explained based on the sample

Table 3
Comparison between skeletal height using Fully's method and estimated skeletal height using regression equations for the direct method.

	Equations	SEE	$TSH_F - TSH_E$		R
			Mean	p-Value	
ISA male					
(1)	0.96(LCL) + 90.86	4.36	−0.260	0.732	0.58
(2)	1.10(MCL) + 82.47	3.73	−0.710	0.276	0.72
(3)	0.93(MCL) + 0.14(UEpL) + 79.42	3.72	0.073	0.911	0.71
(4)	1.24(MCL) − 0.17(BCB) + 86.22	3.75	−0.013	0.984	0.70
(5)	1.02(MCL) + 0.19(UEpL) − 0.16(EpB) + 81.04	3.73	−0.050	0.938	0.72
(6)	1.10(MCL) + 0.16(UEpL) − 0.21(BCB) + 83.78	3.73	−0.527	0.432	0.69
ISA female					
(7)	1.13(EpB) + 68.19	4.18	−1.460	**0.043**	0.77
(8)	1.13(BCB) + 64.42	4.06	−1.063	0.157	0.76
(9)	0.73(EpB) + 0.59(LCL) + 59.62	3.87	−1.163	0.114	0.77
(10)	0.73(BCB) + 0.36(UEpL) + 61.08	3.88	−0.857	0.221	0.79
(11)	0.55(EpB) + 0.53(LCL) + 0.53(VND) + 59.62	3.82	−0.343	0.627	0.78
SAED male					
(12)	1.31(LCL) + 72.32	5.31	−0.067	0.941	0.67
(13)	0.82(UEpL) + 75.64	5.31	0.210	0.810	0.69
(14)	0.50(UEpL) + 0.80(LCL) + 55.63	4.89	0.010	0.991	0.72
(15)	0.53(UEpL) + 0.58(VND) + 0.58(LCL) − 0.22(EpB) + 63.68	4.81	0.020	0.981	0.74
(16)	0.49(UEpL) + 0.54(VND) + 0.53(LCL) + 55.93	4.80	−0.363	0.661	0.74
(17)	0.55(UEpL) + 0.56(VND) + 0.41(LCL) + 0.41(BCB) − 0.49(EpB) + 61.07	4.80	−0.460	0.574	0.75
SAED female					
(18)	1.26(BCB) + 56.96	3.95	−1.287	0.136	0.69
(19)	1.42(LCL) + 61.88	3.93	−0.667	0.411	0.72
(20)	1.21(LCL) + 0.38(EpB) + 48.83	3.78	−0.243	0.755	0.74
(21)	0.67(BCB) + 0.79(LCL) + 52.00	3.71	−1.223	0.116	0.77
(22)	0.37(BCB) + 1.03(LCL) + 0.17(EpB) + 47.07	3.78	−0.353	0.643	0.76
(23)	0.40(BCB) − 0.21(VND) + 1.07(LCL) + 0.23(EpB) + 45.43	3.81	−1.070	0.172	0.75

SEE = standard error of estimate, TSH_F = skeletal height using Fully's method, TSH_E = estimated skeletal height using appropriate regression equation.
Statistically significant values are indicated in bold.

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Table 4
Comparison between skeletal height using Fully's method and estimated skeletal height using regression equations for the indirect method.

	Equations	SEE	$TSH_F - TSH_E$		R
			Mean	*p*-Value	
ISA male					
(1)	0.37(LCL) + 21.23	1.69	−1.563	**0.045**	0.58
(2)	0.41(MCL) + 19.32	1.52	−2.840	**0.000**	0.72
(3)	0.47(MCL) – 0.10(BCB) + 20.88	1.53	2.156	**0.000**	0.69
(4)	0.29(MCL) + 0.11(UEpL) + 17.04	1.47	−3.717	**0.000**	0.69
(5)	0.12(UEpL) + 0.36(MCL) – 0.10(BCB) + 19.14	1.46	−2.930	**0.000**	0.66
(6)	0.12(UEpL) – 0.10(BCB) + 0.37(MCL) – 0.01(LCL) + 19.21	1.48	−3.077	**0.000**	0.66
ISA female					
(7)	0.31(UEpL) + 16.46	1.54	−2.073	**0.010**	0.72
(8)	0.23(UEpL) – 0.17(MCL) + 0.28(VND) + 0.15(LCL) + 16.70	1.48	−2.413	**0.002**	0.77
(9)	0.24(UEpL) + 0.11(EpB) + 15.33	1.53	−0.700	0.314	0.78
(10)	0.26(UEpL) – 0.06(MCL) + 0.28(VND) + 16.14	1.49	−1.267	0.077	0.77
(11)	0.24(UEpL) + 0.25(VND) + 15.03	1.48	−2.633	**0.001**	0.78
(12)	0.04(EpB) + 0.15(LCL) + 0.26(VND) + 0.21(UEpL) – 0.19(MCL) + 16.63	1.50	−0.537	0.430	0.79
SAED male					
(13)	0.30(UEpL) + 16.73	2.21	−0.060	0.945	0.68
(14)	0.25(UEpL) + 0.21(VND) – 0.06(EpB) + 18.31	2.17	1.593	0.066	0.71
(15)	0.23(UEpL) – 0.04(BCB) + 0.22(VND) – 0.16(MCL) + 0.24(LCL) – 0.05(EpB) + 17.81	2.21	0.053	0.950	0.69
(16)	0.22(UEpL) + 0.16(VND) – 0.01(BCB) + 0.13(LCL) + 12.61	2.20	−2.573	**0.003**	0.73
(17)	0.25(UEpL) + 0.21(VND) + 14.20	2.17	0.527	0.522	0.73
(18)	0.22(UEpL) + 0.19(VND) + 0.02(BCB) + 0.24(LCL) – 0.19(MCL) + 12.73	2.19	0.867	0.302	0.72
SAED female					
(19)	0.44(BCB) + 11.42	1.40	−0.467	0.587	0.69
(20)	0.33(BCB) + 0.11(UEpL) + 9.95	1.36	−1.790	**0.043**	0.69
(21)	0.29(BCB) + 0.21(LCL) + 10.10	1.36	−1.677	**0.041**	0.76
(22)	0.22(BCB) + 0.09(UEpL) + 0.17(LCL) + 9.14	1.33	−0.927	0.255	0.74
(23)	0.26(BCB) + 0.11(UEpL) – 0.14(VND) + 0.18(LCL) + 7.81	1.33	−0.490	0.551	0.72
(24)	0.22(BCB) + 0.11(UEpL) – 0.14(VND) + 0.20(LCL) + 0.06(EpB) + 6.26	1.37	−2.417	**0.006**	0.72

Statistically significant values are indicated in bold.

Table 5
Adjusted SEE for regression equations for indirect method.

	Equations	SEE	Adjusted SEE
ISA male			
(1)	0.37(LCL) + 21.23	1.69	6.78
(2)	0.41(MCL) + 19.32	1.52	6.40
(3)	0.47(MCL) – 0.01(BCB) + 20.88	1.53	6.43
(4)	0.29(MCL) + 0.11(UEpL) + 17.04	1.47	6.29
(5)	0.12(UEpL) + 0.36(MCL) – 0.10(BCB) + 19.14	1.46	6.27
(6)	0.12(UEpL) – 0.10(BCB) + 0.37(MCL) – 0.01(LCL) + 19.21	1.48	6.32
ISA female			
(7)	0.31(UEpL) + 16.46	1.54	6.55
(8)	0.23(UEpL) – 0.17(MCL) + 0.28(VND) + 0.15(LCL) + 16.70	1.48	6.40
(9)	0.24(UEpL) + 0.11(EpB) + 15.33	1.53	6.53
(10)	0.26(UEpL) – 0.06(MCL) + 0.28(VND) + 16.14	1.49	6.42
(11)	0.24(UEpL) + 0.25(VND) + 15.03	1.48	6.40
(12)	0.04(EpB) + 0.15(LCL) + 0.26(VND) + 0.21(UEpL) – 0.19(MCL) + 16.63	1.50	6.45
SAED male			
(13)	0.30(UEpL) + 16.73	2.21	7.98
(14)	0.25(UEpL) + 0.21(VND) – 0.06(EpB) + 18.31	2.17	7.88
(15)	0.23(UEpL) – 0.04(BCB) + 0.22(VND) – 0.16(MCL) + 0.24(LCL) – 0.05(EpB) + 17.81	2.21	7.98
(16)	0.22(UEpL) + 0.16(VND) – 0.01(BCB) + 0.13(LCL) + 12.61	2.20	7.95
(17)	0.25(UEpL) + 0.21(VND) + 14.20	2.17	7.88
(18)	0.22(UEpL) + 0.19(VND) + 0.02(BCB) + 0.24(LCL) – 0.19(MCL) + 12.73	2.19	7.93
SAED female			
(19)	0.44(BCB) + 11.42	1.40	6.26
(20)	0.33(BCB) + 0.11(UEpL) + 9.95	1.36	6.16
(21)	0.29(BCB) + 0.21(LCL) + 10.10	1.36	6.16
(22)	0.22(BCB) + 0.09(UEpL) + 0.17(LCL) + 9.14	1.33	6.08
(23)	0.26(BCB) + 0.11(UEpL) – 0.14(VND) + 0.18(LCL) + 7.81	1.33	6.08
(24)	0.22(BCB) + 0.11(UEpL) – 0.14(VND) + 0.20(LCL) + 0.06(EpB) + 6.26	1.37	6.18

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differences and ultimately the effect of positive secular trend on stature in Americans [2].

In the hypothetical case described by Steele [2], the maximum length of femur was estimated using one of the regression equations he derived from a sample of a skeleton obtained from the Terry Collection. However, the equation he used in the estimation of stature from the maximum length of the femur was formulated by Trotter and Gleser [3] using a sample of long bones that were obtained from skeletal remains of military personnel of the Korean War. The limitation regarding sample differences in Steele's [2] study was overcome in the current study. The samples used in the derivation of equations for maximum length of femur as well as those used in the formulation of equations for the estimation of skeletal height were all obtained from the Raymond A. Dart Collection. In addition, the samples are quite similar in terms of dimensions and as such are not constrained by the issue of secular trend.

Steele [2] favoured the use of the indirect method even though it is more complicated compared to the direct method since it is a two-step approach. In contrast to what Steele observed, results of the analyses from the current study showed that the direct method provides a more reliable estimate of skeletal height compared to the indirect method. With the exception of one equation (Table 3), estimates of skeletal height from all equations derived for the direct estimation of skeletal height (TSH_E) from measurements of fragments of the femur showed strong positive correlation with skeletal height using Fully's method (TSH_F). Also, the differences between these two skeletal heights were not only minimal and inconsequential in most cases but also statistically insignificant. These indicate that there is a strong agreement between TSH_{Fully} and TSH_{Est}. However, most of the equations used in the indirect estimation of skeletal height yielded statistically significant differences between TSH_{Fully} and TSH_{Est}. Therefore, it could be inferred that equations used in the direct estimation of skeletal height are more accurate compared to those formulated for the indirect method.

The magnitude of the value of the standard error of estimate is another important factor worthy of consideration as it is considered to be a measure of accuracy of a regression equation. According to Trotter and Gleser [3], Keen in 1953 defined the standard error of estimate as ''a measure of expected accuracy of a stature estimate of an individual who belongs to the same population from which the equation was derived''. A high standard error of estimate indicates a low accuracy and vice versa. A casual look at the range of standard errors of estimate (SEE) for regression equations for the direct (3.71–5.31) and indirect method (1.33–2.21) as shown in Tables 3 and 4 respectively may lead to the erroneous conclusion that the indirect method is the more accurate of the two methods.

However, if one considers the fact that the second step in the estimation of stature from the estimated maximum length of femur requires that the SEE (from the first step as shown in Table 4) should be adjusted, it is expected that the final calculated SEE for the indirect method will be higher than that of the direct method. Steele [2, p. 90] instructed that ''the second step is to adjust the standard error to take into account the fact that the femur length also has a standard error. . .adjustment is made by multiplying the standard error of the estimated femur length by the first constant in the stature regression formula, and then adding the product to the standard error of the estimated stature''. Table 5 shows the SEE for each of the equations in Table 4 after the necessary adjustment using the coefficient and constant from the appropriate equation presented in Table 2. The magnitude of these adjusted SEE (range = 6.08–7.98), expectedly, is higher than that obtained for the direct method (Table 3) which is a further confirmation of the accuracy of the latter method.

5. Conclusion

In the absence of intact long bones, stature reconstruction from measurements of fragments of long bones is essential in the identification process as it complements other demographic information such as sex, age and population affinity. It has been suggested that the indirect method of stature estimation, which involves the initial estimation of maximum length of the femur and subsequent estimation of stature from the estimated femur length, gives a more reliable result. This is contrary to the results of the present study in which the direct method has been shown to be more reliable and is less complicated compared to the indirect method. This study therefore recommends the use of the direct method in situations where such formulae exist. However, in the absence of regression formulae for the direct estimation of stature for fragments of long bones, the indirect method can also yield a reasonable degree of accuracy.

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Appendix Four

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Original Communication

Metatarsals in the estimation of stature in South Africans

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Abstract

To date, only one study has investigated the potential of metatarsals in the estimation of stature for forensic purposes. The morphology of these bones from clinical and paleontological perspectives is well researched in different parts of the world including South Africa. The present study aimed at assessing the usefulness of metatarsals of South Africans in the estimation of stature. For this study, 226 complete skeletons obtained from the Raymond A. Dart Collection were used in the formulation of univariate and multivariate regression equations from six linear measurements of metatarsals. The standard error of estimate for these equations was lower than that obtained for fragments of long bones and other skeletal elements studied so far for stature estimation in South Africans with the exception of intact long bones. Therefore, regression equations presented in this study can provide a reliable estimate of stature in cases where intact long bones are not available for forensic analysis.

Keywords: Stature; Metatarsals; South Africa; Forensic anthropology

1. Introduction

Recent trends in forensic anthropology have shown an increased interest in forensic age diagnosis using regression analysis.[1–4] According to Krogman and Iscan,[5] this statistical theorem was developed by Pearson in 1899 for the purpose of reconstructing stature. Intact long bones of the upper and lower extremities have been subjected to this analysis in Americans,[6,7] South Africans,[8–10] Portuguese,[11] Germans,[12] Bulgarians[13] and Turks[14] for the purpose of stature estimation. Since long bones are not recovered in their intact state in all forensic cases, researchers have also formulated regression equations from the skull,[15–17] metacarpals,[18,19] measurements of fragments of long bones,[20–24] and talus and calcaneus.[25–27] Recently, efforts have also been made at estimating stature from measurements of percutaneous bones,[28] as well as dimensions of the hands, feet and shoe prints.[29–31]

It is essential that the forensic application of foot bones such as the metatarsals, which have a good chance of being recovered, be investigated. While numerous studies have been conducted on the morphology of metatarsals from both clinical and paleoanthropological perspective, of which Zipfel[32] provided a detailed account, few researchers have investigated the usefulness of metatarsals for forensic purposes.[33,34] Byers et al.[33] made the first and only attempt to date at using the length of metatarsal bones for stature estimation. They used 130 skeletons derived from the Terry Collection at the Smithsonian Institute and Maxwell Museum of Anthropology of the University of New Mexico. Six measurements of metatarsals were used for the derivation of regression equations for estimation of stature in African and European Americans.

Since no study has been conducted on stature estimation from measurements of metatarsals in South Africans, it was the aim of this study to assess the usefulness of the length of metatarsal bones in the estimation of stature of South Africans of European descent and indigenous population groups.

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2. Materials and methods

A total of 226 complete skeletons were selected by a simple random sampling technique from the Raymond A. Dart Collection of human skeletons housed in the School of Anatomical Sciences of the University of the Witwatersrand, Johannesburg. In the selection process, consideration was given only to the two biggest groups in the collection namely the indigenous South African (ISA) and South African of European descent (SAED) population groups. While different tribes constitute the ISA population group, they were treated as a single homogeneous group because previous studies have shown that no statistically significant intertribal differences exist in the osteometric dimensions.[35,36]

The SAED population group on the other hand consists of migrants mainly from the Netherlands and other European countries.[37] It has been shown that their osteometric characteristics are different from those of Europeans and American whites.[37] The documented ages of selected skeletons ranged between 29 and 75 years. The selected skeletal materials represent 60 ISA males, 53 ISA females, 58 SAED males and 55 SAED females.

Complete skeletons with elements that constitute stature namely complete skull (with skull cap), vertebrae, femur, tibia, talus and calcaneus were used. Skeletons with missing elements such as skull caps, broken edges and those with excessive osteophytic lipping were excluded. For each selected skeleton, total skeletal height (TSH) was estimated using Fully's method[38] because previous studies by Lundy[36] and Bidmos[39] have shown that most documented cadaver lengths that form part of the catalogue of skeletons in the Raymond A. Dart Collection are not reliable.

Measurements that were taken for the calculation of TSH as described by Fully[38] and Bräuer[40] are as follows:

1. Basi-bregmatic height of the skull using a spreading caliper.
2. Maximum heights of vertebrae (C2-S1) using a sliding caliper.
3. Physiological length of the femur using an osteometric board.
4. Lateral condylomalleolar length of the tibia using an osteometric board.
5. Articulated height of the talus and calcaneus using an osteometric board.

In addition, six linear measurements of metatarsal bones were taken using a vernier caliper. Measurements of lengths of first to fourth metatarsals were taken using the same technique as described below. However, two length measurements (functional and morphological) were taken of each fifth metatarsal. All these measurements were as defined by Bräuer[40]:

(i) Lengths of metatarsals 1–4 (M1–M4): The linear distance from the apex of the capitulum to the midpoint of the articular surface of the base parallel to the longitudinal axis of the bone.
(ii) Functional length of the fifth metatarsal ($M5_F$): The linear distance between the apex of the capitulum and the dorsoplantar midpoint of the intersection between the fourth metatarsal and cuboid facets.
(iii) Morphological length of the fifth metatarsal ($M5_P$): The linear distance between the apex of the capitulum and the tip of the tuberosity.

Means and standard deviations for TSH and metatarsal measurements were obtained for each group. Regression analyses were then performed in stages after establishing that (i) data for each group followed a normal distribution pattern, (ii) variances did not show significant sex differences; and (iii) all measurements displayed high reliability. TSH was regressed on individual and various combinations of lengths of metatarsals. From these analyses, the correlation coefficient (r), standard error of estimate (SEE), regression coefficient and constant were obtained. Simple and multiple regression equations were formulated from the coefficients and constants.

3. Results

Means and standard deviations for total skeletal height (TSH) and each of the metatarsal measurements for ISA and SAED are presented in Table 1. Males consistently presented with higher mean values compared to females ($p \leqslant 0.0001$) with regard to TSH and all metatarsal measurements.

Table 2 shows regression equations that can be used in the estimation of stature from individual lengths of

Table 1
Descriptive statistics

Measurements	Males			Females			*F*-statistic	*p*-Value
	n	Mean	SD	*n*	Mean	SD		
ISA								
TSH	60	153.10	5.25	53	142.60	6.82	85.143	0.000
M1	60	63.14	3.40	53	59.89	3.78	22.587	0.000
M2	60	75.56	3.41	53	71.11	4.30	37.810	0.000
M3	60	70.51	3.65	53	68.00	4.52	10.620	0.001
M4	60	71.26	3.61	53	66.08	4.42	46.962	0.000
$M5_F$	60	61.44	3.35	53	58.53	4.14	17.029	0.000
$M5_P$	60	72.13	4.54	53	68.61	5.35	14.311	0.000
SAED								
TSH	58	157.65	6.92	55	147.11	6.13	73.153	0.000
M1	58	62.94	4.39	55	59.98	3.22	16.555	0.000
M2	58	76.41	5.04	55	72.29	4.16	22.326	0.000
M3	58	71.64	4.75	54	67.85	4.22	19.815	0.000
M4	58	70.10	4.64	54	65.90	4.16	25.304	0.000
$M5_F$	58	62.30	4.73	55	59.05	3.92	15.723	0.000
$M5_P$	58	73.05	5.02	55	68.50	5.27	22.094	0.000

ISA: Indigenous South Africans; SAED: South Africans of European descent; TSH: total skeletal height; M1–M4: length of metatarsals 1–4; $M5_F$: functional length of fifth metatarsal; $M5_P$: physiological length of fifth metatarsal.

Table 2
Equations for stature estimation (in cm), correlation and standard error of estimate using individual measurements

Equations		Correlation	SEE
ISA male			
1	$0.96M1 + 92.67$	0.62	4.16
2	$0.96M2 + 80.62$	0.62	4.14
3	$0.87M3 + 91.75$	0.60	4.22
4	$0.64M4 + 107.42$	0.44	4.76
5	$0.83M5_F + 102.31$	0.53	4.50
6	$0.68M5_P + 103.92$	0.59	4.28
ISA female			
1	$1.30M1 + 64.97$	0.72	4.79
2	$1.13M2 + 61.99$	0.72	4.81
3	$1.05M3 + 71.04$	0.70	4.94
4	$1.03M4 + 74.50$	0.67	5.12
5	$1.03M5_F + 82.43$	0.62	5.38
6	$0.69M5_P + 95.39$	0.54	5.80
SAED male			
1	$0.91M1 + 100.49$	0.58	5.71
2	$0.96M2 + 84.00$	0.70	4.97
3	$0.98M3 + 87.41$	0.67	5.16
4	$0.98M4 + 88.65$	0.66	5.24
5	$0.96M5_F + 97.73$	0.66	5.26
6	$0.83M5_P + 97.19$	0.61	5.54
SAED female			
1	$1.39M1 + 63.57$	0.73	4.22
2	$1.07M2 + 69.98$	0.72	4.28
3	$1.01M3 + 78.78$	0.69	4.54
4	$1.00M4 + 81.00$	0.68	4.56
5	$0.97M5_F + 89.89$	0.62	4.86
6	$0.74M5_P + 96.61$	0.63	4.79

metatarsals for each biological group. In the ISA group, moderate positive correlation was obtained between all measurements and TSH in the male sample (0.44–0.62) while females presented with moderate to high correlations (0.54–0.72) (Table 2). In the SAED group, the range of correlation obtained for males (0.58–0.70) was similar to that obtained for females (0.62–0.73). M2 to M4 consistently showed high correlation in all groups except for the male ISA sample. The lowest correlation (0.44) was obtained in this group for M4 while the highest correlation of 0.73 was shown by M1 in the SAED female sample (Table 2).

The lowest standard error of estimate was obtained for the equation that utilized M2 in the ISA male group (4.14) while that for physiological length of M5 in the ISA female group (5.80) presented with the highest value of SEE (Table 2). The standard error of estimate for these equations ranged between 4.14 for ISA males (function 2) and 5.80 for ISA females (function 6). In estimating stature from equations presented in Table 2, it is advised that equations with high correlation coefficients and low standard errors of estimate should be used for each biological group. Regression equations presented for M2 in all groups consistently fit this profile.

Presented in Table 3 are the best multivariate equations with reasonable application. A higher range of correlation coefficient (0.67–0.76) and lower standard error of estimate (3.81–5.07) were obtained which indicates a higher degree of accuracy of regression equations derived from combination of measurements.

Table 3
Equations for stature estimation (in cm), correlation and standard error of estimate using combination of measurements

Equations		Correlation	SEE
ISA male			
1	$0.64M1 + 0.39M5_P + 85.07$	0.67	3.96
2	$0.58M1 + 0.99M2 - 0.52M4 + 79.44$	0.69	3.92
3	$0.54M1 + 0.75M2 - 0.61M4 + 0.35M5_P + 81.15$	0.71	3.81
4	$0.53M1 + 0.68M2 + 0.21M3 - 0.54M4 - 0.33M5_F + 0.43M5_P + 81.66$	0.72	3.85
ISA female			
1	$0.81M1 + 0.53M3 + 58.21$	0.75	4.58
2	$0.81M1 + 0.70M3 - 0.17M5_P + 58.46$	0.76	4.60
3	$0.71M1 + 0.34M2 + 0.49M3 - 0.20M5_P + 56.54$	0.76	4.62
SAED male			
1	$0.71M2 + 0.31M5_F + 83.69$	0.71	4.96
2	$0.58M2 + 0.31M5_F + 0.17M5_P + 81.90$	0.71	4.98
3	$0.78M2 - 0.50M4 + 0.47M5_F + 0.28M5_P + 82.61$	0.72	4.98
4	$0.02M1 + 0.87M2 - 0.29M3 - 0.35M4 + 0.49M5_F + 0.30M5_P + 82.27$	0.72	5.07
SAED female			
1	$0.81M1 + 0.53M2 + 60.32$	0.75	4.10
2	$0.84M1 + 0.65M2 - 0.16M5_F + 59.92$	0.76	4.12
3	$0.85M1 + 0.59M2 - 0.38M5_F + 0.22M5_P + 61.92$	0.76	4.14

4. Discussion

Trotter and Gleser[6,7] conducted arguably the biggest studies on stature reconstruction. They[6,7] concluded that since regression equations are population and sex-specific, anthropologists should limit the use of such equations to the population and sex groups from which the equations were derived. Many other studies are in agreement with this observation.[8–11,18–20,25,26] Contrary to the widely accepted recommendation of Trotter and Gleser,[6,7] Byers et al.[33] presented equations for combined data for male, female and all samples in addition to those derived for each biological group. They[33] combined data for Afro-American ($n = 9$) and Euro-American ($n = 57$) males to derive a common equation for males. A similar procedure was carried out for Afro-American ($n = 7$) and Euro-American ($n = 49$) females. Finally, they[33] combined data for the four biological groups in an attempt to derive a single equation for stature estimation for Americans of both population groups and sexes.

This effort can be justified in a situation where only metatarsal bones are available for forensic analysis. Since this is a very unlikely situation, the reason for deriving such equations is unknown. Since the distribution of sample size in the study[33] has a greater preponderance of Euro-American individuals, it will therefore render the combined equation biased towards that population group. It can be inferred that if there is a statistically significant difference between mean measurements for the two population groups for each sex, the equations will significantly overestimate or underestimate stature of the Afro-American group. Since the authors[33] failed to present descriptive statistics for samples used, no comparison could be made between the biological groups they studied and samples used in the present study. A comparison of mean measurements of metatarsal lengths in the current study (Table 1) showed statistically significant sex differences for each population group. This is in support of observations made from previous studies on foot bones[25,26] thereby confirming sexual dimorphism of metatarsals.

Byers et al.[33] reported moderate to strong relationships between metatarsal lengths and stature with correlation coefficients that ranged between 0.59 and 0.89. Most of these coefficients were greater than 0.60. A similar result was obtained in the present study. All metatarsal lengths showed a moderate to strong correlation with TSH except M4 (ISA male) and $M5_P$ (ISA male and female) that presented with coefficient of less than 0.6. The accuracy of regression equations from the Byers et al.[33] study and the present study are also worth comparing.

The accuracy of a regression equation in the estimation of stature depends on the value of its standard error of estimate (SEE). This is defined as a measure of the expected accuracy of a regression equation in the estimation of the stature of an individual from the same population group from which the equation was originally derived. A high value for SEE suggests a low accuracy and vice versa. The range of SEE for regression equations for estimation of stature using individual metatarsal lengths in ISA males was similar to that obtained for SAED females (Table 2). These equations presented with lower SEEs compared with those obtained for ISA females and SAED males (Table 2). The range of SEEs from multivariate equations (3.81–5.07) was slightly lower than that obtained for univariate equations (Table 3). Therefore, regression equations derived from combinations of measurements will present better accuracy compared to those formulated from single variables.

In the Byers et al.'s[26] study, the best accuracy was obtained for regression equations that utilised M3 for the African American female group (3.99) while the lowest accuracy was obtained for the regression equation using M5 (functional) for the combined data group (7.6). This range is higher than that obtained in the present study (3.81–5.07) which indicates a better predictive accuracy of equations derived in this study. Also, the SEEs obtained from previous studies in South Africa for the calcaneus (4.0–6.3), fragments of tibia (5.2–6.7) and skulls (4.4–6.2) were higher than those found in the present study (3.7–5.3). However, regression equations derived for intact long bones (SEE for ISA = 1.8–5.3, SEE for SAED = 1.8–5.5) will provide a more accurate estimate of stature compared with those formulated in this study.

5. Conclusion

Lengths of metatarsals showed moderate to high correlation with total skeletal height which indicates a good association between predictor and dependent variables. Standard error of estimate for derived regression equations is lower than those obtained for the skull, fragments of tibia and the calcaneus which shows that metatarsals have a better predictive efficacy in stature estimation compared to these skeletal elements. Since SEE of regression equations derived for intact long bones is lower than that presented in the present study, it is recommended that stature should be estimated from these bones when they are available for forensic analysis. In their absence, regression equations presented in this study can provide a reliable estimate of stature.

Conflict of Interest

None declared.

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Appendix Five

Participant information leaflet and informed consent

PARTICIPANT INFORMATION LEAFLET AND INFORMED CONSENT

STUDY NUMBER: MO81137

STUDY TITLE: Soft tissue evaluation as a correction factor for stature estimation

SPONSOR: None

INVESTIGATOR: I am Dr Mubarak Bidmos, a medical practitioner at Kimberley Hospital Complex and a registered postgraduate student at the University of the Witwatersrand, Johannesburg.

INSTITUTION: University of the Witwatersrand, Johannesburg

DAYTIME AND AFTER HOURS TELEPHONE NUMBER (S): 0826453792

To the Participant: This *consent form may contain words that you do not understand. Please ask me (Dr M Bidmos) or my supervisor (Prof P Manger) to explain any words or information that you do not clearly understand. You may take home* ***an unsigned copy of this consent*** *form to think about or discuss with family or friends* ***before making your decision.***

1. INTRODUCTION:

This is to invite you to take part in a research study in which your participation is entirely voluntary.

1. Before agreeing to participate, it is important that you read and understand the following explanation of the purpose of the study, the study procedures, benefits, risks, discomforts, and precautions. You have every right to withdraw from the study at any time.

   This information leaflet is to help you to decide if you would like to participate. You should fully understand what is involved before you agree to take part in this study.

2. If you have any questions, do not hesitate to ask me (Dr M Bidmos) or my supervisor (Prof P Manger).

3. You should not agree to take part unless you are satisfied about all the procedures involved.

4. If you decide to take part in this study, you will be asked to sign this document to confirm that you understand the study. You will be given a copy to keep.

2. PURPOSE OF THE STUDY

South Africa has a very high crime rate which affects all irrelevant of population group. However, being a member of the biggest of the four population groups in the country, you are been invited to consider taking part in the research that will assist in establishing equations that could be used in better identifying indigenous South Africans from their skeletal remains.

The purpose of this study is to derive regression equations for the estimation of stature of adult indigenous South Africans using Magnetic resonance imaging technique. The result of this study will be compared with those that have been conducted using dried skeletal materials.

3. LENGTH OF THE STUDY AND NUMBER OF PARTICIPANTS:

- The study will be performed in South Africa only
- Approximately 60 participants will participate in this study.
- Participants will be enrolled at School of Anatomical Sciences, Medical School of the University of the Witwatersrand, Johannesburg and Donald Gordon-Wits Medical Centre. The participants will be between the ages of 25 and 50 years.
- The total amount of time required for your participation in this study will be a maximum of one hour.

4. PROCEDURES:

- If you agree to take part in this study, you will be questioned on your past medical and surgical history, and examined for any abnormality of the spine before you qualify for this study
- Your date of birth will also be asked for and you may need to provide an ID document to confirm this.
- Your height will then be measured while in the standing position using a stadiometer at the School of Anatomical Sciences
- Thereafter, your full body magnetic resonance image will be taken at the Donald Gordon-Wits Medical centre

5. WILL ANY OF THESE STUDY PROCEDURES RESULT IN DISCOMFORT OR INCONVENIENCE?

A magnetic resonance imaging is a diagnostic procedure that exposes you to a negligible amount of radiation. It will not cause you any discomfort or inconvenience.

6. BENEFITS:

- You may not benefit directly from this study
- However, your participation in this study will contribute to the development of the field of forensic science in South Africa which will assist law enforcement agents in identifying individuals from their skeletal remains.

7. BENEFITS AND RISKS OF STANDARD : Are there any warnings or restrictions concerning my participation in this study?

- If you are pregnant or breastfeeding or planning to become pregnant during the study period, you may not take part in the study

8. RIGHTS AS A PARTICIPANT IN THIS STUDY:

- Your participation in this study is entirely voluntary and you can decline to participate, or stop at any time, without stating any reason.
- You will NOT suffer any job loss or institutional sanctions should you decline to participate or stop participation at any time.
- All information obtained from you will be treated with utmost confidentiality.

9. WITHDRAWAL:

- I retain the right to withdraw you from the study if it is considered to be in your best interest.
- If you did not give an accurate history or did not follow the guidelines of the study and the regulations of the study facility, you may be withdrawn from the study at any time.

10. CONSENT

- I, --have read the above and fully understand the content of this information sheet and do consent to participate in this study.

  Signature -------------------------------------- Date--------------------