CHAPTER 3

LITERATURE REVIEW - STATURE DETERMINATION

3.1 Introduction

In many forensic cases, the soft tissue of human remains recovered at a crime scene, has often degenerated to such a point that demographics such as population affinity, age, sex and living height cannot be ascertained with accuracy. Most often, only skeletal parts are recovered, rather than the entire skeleton, which then serves as the only available resource to estimate the height of an unknown person. The role of the forensic anthropologist, in such cases, is to then determine and assess the characteristics of such remains through various methods of analyses in order to establish the identity of an unknown individual. One such characteristic is that of height measurement.

Stature is a unique biological entity in that it can be estimated not only in the living individual, but also from a skeleton long after the death of a person (Ryan & Bidmos 2007). In order to assess height from human remains, an understanding of it in a living person is crucial. Stature has been shown to steadily increase from infancy to adulthood. It remains stable throughout middle age and then decreases with old age (Sjøvold 2000). Ageing is not the only factor that causes a reduction in height. In fact, in a living individual, it has been shown to decrease by approximately 2 cm per day. This is from the time a person wakes up and carries out their various daily activities throughout the course of the day, to the time that an individual goes back to sleep at night. This reduction in height that occurs with continuous postural changes is ascribed to loss of elasticity in the intervertebral discs. This happens to such an extent that there is compression of the cartilages with resultant approximation of adjacent vertebrae (Sjøvold 2000).

Due to the variability in height, various approaches to the study of human growth and development have evolved. These methods may be theoretical, non-theoretical, descriptive or quantitative. Data on growth and development obtained by statistical analyses on a human population sample can be and is used to derive standard references for parameters such as height. These standard references are designed into equations which are then used to assess growth, development, nutritional status, social and cultural circumstances of an individual or a population (Tanner 1981, Bogin 1988, Malina *et al*. 2004).

Gigantism or dwarfism is said to occur when there is a 20 percent deviation of height from the average. The problem in such instances is to establish what the average is for an individual in a particular population (Bogin 1988, Kottak 1997, Steyn & Smith 2007). It has been suggested that adult height in males or females of a particular ethnic group should follow a normal distribution pattern (Bogin 1988).

Bogin (1988) reported that on average, men are taller than women and that growth in height tends to come to a halt when the growing end of a long bone, namely the epiphysis, fuses with the diaphysis (shaft) of the bone. At this point, the long bone is said to have reached its peak length.

While stature is an entity that is seen to vary in the living individual, its inherent characteristic makes it an important contribution to the identification process (Krogman & İşcan 1986). Estimation of antemortem or living stature from a skeleton forms an important part of the forensic analyses. It must therefore be estimated in a way that adjustments can be made as closely as possible to that measured on the living individual (Trotter 1970). The actual height measured from an individual or cadaver is often referred to as the biological stature and is more accurate than forensic stature (Ousley 1995). The latter is an estimate rather than the actual recording of an individual's height. Such estimates of stature are often encountered when relatives report the height of an individual as short, medium or tall (Kottak 1997, Saferstein 2004, Rich *et al*. 2005, Steyn & Smith 2007).

Intact long bones recovered amongst human remains, is ideal to reconstruct stature of an unidentified individual. However, this is not always possible in many forensic cases as fragments of long bones are often encountered. In order to assist with identification of such forensic cases, researchers have formulated regression equations from the skull (Chiba & Terazawa 1998, Patil & Mody 2005, Ryan & Bidmos 2007), metacarpals (Musgrave & Harneja 1978, Meadows & Jantz 1992), long bone fragments (Steele & McKern 1969, Mysorekar *et al*.

1980, Simmons *et al*. 1990, Holland 1992, Ozaslan et al. 2003, Chibba & Bidmos 2007), hand and foot dimensions and shoe prints (Ozden *et al*. 2003, Krishan & Sharma 2007) and metatarsals (Byers *et al*.1989, Robling & Uberlaker 1997).

In circumstances where bodies have been recovered from mass disasters or at the scene of a crime, or in cases where the corpse has been severely mutilated, decomposed or fragmented, stature can only be determined by measuring parts of the skeleton that are available (Sjøvold 2000). The height of the individual is often related to the relative size of the skeletal bone or fragment under study. In other words, the larger the bone, the taller the individual is expected to be (Sjøvold 2000). The aim of forensic anthropologists is to put together as many systematic studies in order to identify fragmented and dismembered human remains as accurately as possible (Ozaslan *et al*. 2003).

Another problem added to the identification process is that of variation in a single bone or in the entire skeleton as well as in skeletons of a larger sample. Knowledge of this variation is essential to forensic anthropologists as it interferes with the identification process (Krogman and İşcan 1986). Studies on assessing human variation carried out by a number of physical anthropologists have contributed to forensic cases (Bogin 1988, Kottak 1997, Malina *et al*. 2004). Due to the existence of these variations, the likelihood of errors occurring when determining stature is inevitable, not only in a single skeleton but also in a population. To overcome the problem of variation, a correlation analysis needs to be carried out. The higher the correlation between bone measurements and stature, the more accurate the estimation of stature is likely to be. The opposite is true in cases where the correlation is low (Sjøvold 2000).

Population differences in stature have drawn great interest worldwide. The ability to allocate skeletal remains as accurately as possible to a specific population depends on whether such a group exists as well as on the availability of the sample which represents the specific population (Brickley & Fellini 2007). In fact, differences in height as well as the rate of growth between different populations have been ascribed to various hereditary and environmental factors (Trotter & Gleser 1951, Bogin 1988). Bogin (1988) showed that young adult males and females from the Netherlands are relatively the tallest people when compared to Americans, Turkana pastoralists, Japanese, Guatemalan Indians and Bolivian Indians with the African Mbuti pygmy being the shortest people.

One other factor that has also received attention is the effect of secular trends on height. Tobias (1975) was one of the first authors to illustrate the existence of a secular trend towards an increase in adult stature and stated that it did not always have a positive effect. A negative or absent trend can exist in various populations (Tobias 1975, 1985, Tobias & Netscher 1977, Cameron *et al*. 1989).

3.2 Literature review

3.2.1 Historical background

The determination of the individuality of a skeleton involves an in-depth understanding of the skeletal biology, related anomalies, pathology, health and disease status (Krogman & İşcan 1986). Demographic factors such as age, sex and race need to be established when identifying human remains. Once these characteristics have been confirmed, the stature of the individual is then recorded.

The concept of determining stature from long bones is said to have developed as early as the 1700's where maximum length of bones was first recorded by a French anatomist on foetuses and adults (Steele 1970). This interest in stature continued into the 1800's with emphasis on differences between cadaver height and living stature (Steele 1970). To address these differences, the relationship between stature and long bone length was attempted by British researchers whose methods differed slightly from those of the French. These researchers made adjustments for measurements of the femur and multiplied the length of this long bone by a given number. A mathematical method was thus established towards the end of the 1800's (Steele 1970).

Various methods were approached to measure the length of bones. In 1859, a French medical anthropologist, Paul Broca, designed an osteometric board in order to accurately measure bone lengths. His successor, Paul Topinard, published a series of papers between the period of 1885 and 1888 which included mathematical methods regarding the ratio of long bones to stature (Steele 1970).

In 1888, Rollet compared lengths of long bones from male and female cadavers which were measured before and after maceration. This he did to establish whether different values would be obtained in fresh and dried bones (Trotter & Gleser 1952, Steele 1970, Krogman & İşcan 1986). This study was probably also the first to mention sexual dimorphism. Rollet's results showed a difference of about 2 mm between fresh and dried bones (Krogman & İşcan 1986). Studies on cadavers have shown that the drying process following maceration, causes shrinkage of the skeleton and that a 2 mm difference could affect calculation of stature by as much as 4-6 mm (Trotter & Gleser 1952).

In 1893, Rollet's data was re-evaluated by Manouvrier who recommended that this 2 mm difference should be added to the dried bone length. Thereafter, 20 mm should be subtracted from the cadaver stature to obtain living stature. It was only 50 years later that regression formulae for accurate stature estimation for males and females were established (Trotter & Gleser 1951, 1952, Steele 1970, Lundy 1983, Krogman & İşcan 1986, Lundy & Feldesman 1987, Dayal 2002).

Since these earlier years, many studies emerged regarding the incorporation of these regression equations into various human population studies. Problems that arose from later studies are that many of these equations were applied across populations. This brought into question the accuracy of recorded data from studies which used the Trotter and Gleser regression equations and applied it to populations far removed from those for whom the equations were initially intended for (Trotter & Gleser 1951, 1952). Regression equations are population specific and one should be careful when using these formulae in different groups (Lundy 1983). An example of using equations across populations is the study carried out by Stevenson in 1929, where this author used Pearson's regression formula for a Chinese cadaver sample which yielded unfavourable results for this population (Steele 1970).

Equations that were devised by Trotter and Gleser in the early 1950's for Americans were being continuously revised using data from different sources. In 1977, they proposed new equations using the radius and ulna. These equations were applied to forensic cases where results proved unsuccessful. The conclusions drawn from the methods used to derive the Trotter and Gleser equations, included inconsistency as it was not clear from published papers as to whether the malleolus of the tibia had been included or excluded in the measurements (Jantz 1992, Jantz *et al*. 1994, 1995).

3.2.2 Studies on prehistoric material

Stature, in humans, has contributed to various aspects of hominid development (Pilbeam & Gould 1974, Blumenberg 1984). Regression equations established for modern populations have been used to estimate stature of fossil hominids. However, these have been shown to be unreliable, presenting with numerous problems (Musgrave & Harneja 1978, Himes & Roche 1982).

Hens *et al*. (1998) encountered difficulties when attempting to predict stature or body length in a modern and fossil hominid sample using the same regression formulae. The inverse calibration method is used by researchers carrying out archaeological and forensic studies (Hens *et al*. 1998). In a sample where one assumes that equal allometries exists, it has been suggested that the classical calibration be used especially if extrapolating the study to larger or smaller animal (Hens *et al*. 1998). In fossil studies, researchers are often faced with the problem of not knowing whether allometries between the reference sample and a sample of isolated or commingled bones does exist or not (Hens *et al*. 1998).

Allometric techniques have been used to compare weight and stature in Plio-Pleistocene hominids and modern humans with the aim of being able to predict these parameters with a certain degree of accuracy (Aiello 1992). In such studies, the argument may arise as to which allometric technique would be the best to estimate the functional relationship between two variables under study. Studies by Trotter and Gleser (1951, 1952) were not excluded from prehistoric studies. Their regression equations for human populations have found their way into studies on Plio-pleistocene hominids (McHenry 1974).

Hens *et al.* (1998), in their study on determining body length from femur length, employed five commonly used statistical methods to a sample of humans and thereafter applied it to the African ape. In the first instance, they regressed body length to long bone length which is an inverse calibration. Secondly, they regressed long bone length to body length which they referred to as a classical calibration. Thirdly, they computed the major axis regression of body length on long bone length. Fourthly, they calculated reduced major axis regression of body length on long bone length and finally, they used the ratio of long bone to body length.

Attempts by palaeoanthropologists to reconstruct stature of fossil hominids, using the Trotter and Gleser equation, proved unsuccessful as the results overestimated height (Lovejoy & Heiple 1970, McHenry 1974). Even the use of classical formulae or equations developed from a population that closely resembles the height of, for example Australopithecines, resulted in marked differences (Olivier 1976). Other researchers have used regression formulae from various postcranial elements on prehistoric Native Americans to regress stature (Sciulli & Giesen 1993). The disadvantage of any study attempting to determine stature in a prehistoric sample is that the actual stature will never be known. Mathematical methods derived are only able to provide some idea of what the actual height may have been.

3.2.3 Bones used to estimate stature

Ideally, a complete skeleton is preferred when determining stature. While this may not always be possible in many forensic cases, single intact or fragmented bones of the skeleton are used. Of all the bones available for the estimation of stature, the human femur, being the largest and most robust long bone in the skeleton, makes it the bone of choice when reconstructing stature (Trotter & Gleser 1958, Genoves 1967, Lundy 1985). Besides being the largest and most robust bone, the intact femur also has the highest correlation to stature and is thus widely used to derive regression equations (Bidmos 2008). Research has shown that the relationship of femoral length to stature is constant and population but not sex specific

(Feldesman 1992, Sjøvold 2000). The contribution of the femur to total stature is 26.75% while the stature/femur ratio has been calculated as 3.74 for all populations (Sjøvold 2000).

Numerous other studies have also used long bones, namely, the humerus, radius, ulna, femur, tibia, and fibula, for estimating stature (e.g., Telkka *et al*. 1962, Genoves 1967, Olivier *et al*. 1978). Some studies have excluded measurements of dried bones such as the tibia, as it yields unsuccessful results when compared to that of living stature (Allbrook 1961). Estimation of stature in Asiatic Indians (Singh & Sohal 1952, Jit & Singh 1956) using the clavicle, computed standard error of estimates as high as 32 cm. Such a high error value would exclude the clavicle from being used in forensic cases. Similar attempts to use the scapula in estimating stature, proved unsuccessful (Musgrave & Harneja 1978).

In the 1800's, the vertebral column was not used at all in studies on stature determination, as the absence of one or more vertebrae could render a study invalid and unreliable. The earliest study carried out on stature using the spine, was in 1894 by Dwight (Tibbetts 1981). While the results from this study indicated that the spine can be used to estimate stature, it cannot readily be used in forensic cases as it needs to be in the fresh intact state (Tibbetts 1981). In 1960, Fully and Pineau used the lengths of thoracic and lumbar vertebrae of white European males to devise regression formulae for estimate the length of the vertebral column (Tibbetts 1981). A similar study was carried out on American blacks by Tibbetts (1981), who reported standard errors in the estimates ranging from 67.89 to 54.72 mm for males and 68.22 to 53.09 mm for females. Tibbetts concluded that while the vertebral column can be used to estimate stature, the high errors obtained indicate that it is not the best variable when compared to the low standard error estimates from long limb bones lengths. Jason and Taylor (1995) estimated stature from the lengths of cervical, thoracic, and lumbar segments of the spine in American whites and blacks. Pelin *et al.* (2005) measured dimensions of the sacrum and coccyx from magnetic resonance images of 42 male adults. Statistical analyses of this study indicated that a combination of the sacrococcygeal variables proved to be better predictors for stature than equations derived from individual vertebrae. Furthermore, the equations for the combined variables proved to be better predictors than that given for the foot and head but worse than equations based on long bone lengths.

Celbis and Agritmis (2005) estimated stature using the length of the radius and ulna recorded from a Turkish corpse sample. While recording measurements from corpses is not a standard anthropological method, these authors acknowledge that their study is applicable to accurate determination of antemortem stature and that their regression formulae may need adjustments. Furthermore, these authors report that the lengths of the radius and ulna are 30 mm longer in males than in the females. They obtained correlation values of 0.62 and 0.64 in males and 0.76 and 0.85 in females for the ulna and radius respectively. These authors concluded that dried bone measurements are better estimates of stature than recently deceased individuals. Byers *et al*. (1989) used the lengths of metatarsals to calculate stature.

In their study on Japanese cadavers, Chiba and Terazawa (1998) recorded the diameter of the skull, its circumference as well as the sum of the two variables. The skull measurements were regressed to the length of the cadaver. These authors reported correlation values ranging from 0.32 to 0.53 with a range of the standard error of estimates being 6.59 to 8.59. Patil and Mody (2005) recorded the skull length from lateral cephalometric radiographs to derive at a regression equation for stature. Ryan and Bidmos (2007) reported moderate correlation values ranging from 0.40 to 0.54 with standard error of estimates of 4.37 and 6.24 for their indigenous South African sample. Ryan and Bidmos suggested that while the skull can be used in estimating stature, caution be exercised when it comes to its use in forensic cases. They reiterated the use of long limb bones if available, rather than the skull, to identify human remains.

While conventional methods of estimating stature are dependent on the use of long bones, fragmented bones may be the only available parts of human remains presented to forensic anthropologists. The main problem with using fragments of bone, is the difficulty in identifying landmarks on these samples (Simmons *et al*. 1990, Steele & McKern1969, Steele 1970).

Simmons *et al*. (1990) developed new regression equations for the Terry Collection. These equations were not only for estimating maximum femoral length for stature, but also for three well-defined segments of the femur, namely, the proximal, middle and distal ends. At the proximal end, they measured the vertical diameter of the femoral head and neck and upper breadth. In the midshaft, they recorded the minimum transverse diameter while at the distal end, the parameters were height dimensions of the medial and lateral condyles. By using a fragment of the femur, these authors were able to regress it to maximum femoral bone length. The maximum femoral length in turn was then regressed to stature. The standard error of the estimates, however, was also increased. The proximal femoral breadth yielded the highest correlation value (0.587) in males, while the lateral condyle height in females gave the highest correlation (0.677). Generally, their results showed correlations which were not higher than 0.65. These authors acknowledged that the relationship of bone fragments to stature present with lower prediction accuracies and higher standard errors in comparison to long limb bones.

Holland (1992) estimated stature from fragmented tibia. Five measurements of the proximal tibial end was used, namely, length and width of the lateral and medial tibial condyles as well as bicondylar width. Standard errors for this study ranged from 3.69 to 5.92 cm.

Numerous studies on estimating stature from hand and finger length recorded on living subjects have been carried out (Saxena 1984, Tyagi *et al*. 1999, Jasuja & Singh 2004). In their study of the Indian population, Jasuja and Singh (2004) recorded correlation values ranging from 0.215 to 0.681 in males and 0.279 to 0.622 in females. Standard errors for this group were given as a range from 4.033 to 4.82 in males and 5.061 to 5.127 in females. Radiographic studies have also been taken from living subjects to estimate stature from the length of hand bones (Himes *et al*. 1977).

Musgrave and Harneja (1978) used the length of metacarpals from radiographs to estimate stature. They recorded the inter-articular (physiological) length which was adjusted to compensate for radiographic enlargement. These radiographs were taken from adult male and female patients. The results of their linear regression analysis, where stature was regressed on the length of each metacarpal bone, gave correlation values ranging from 0.53 to 0.67 in males with standard errors of 5.49 to 6.30 cm. In their female group, correlation values ranged from 4.71 to 8.15 with standard errors of 4.70 to 8.14.

Meadows and Jantz (1992) studied the relationship between the length (mm) of a metacarpal and stature (cm) in American white and black males and females. They recorded measurements from the middle of the proximal articular surface to the middle of the distal tip. These authors reported correlation values for males ranging from 0.565 to 0.828 with standard errors from 4.68 to 5.96 cm. Correlation values for their female group ranged from 0.61 to 0.79 with standard errors of 4.68 to 5.96. According to Byers (2005), the standard errors reported by Meadow and Jantz (1992) are large and suggested that metacarpals should not be used for estimating stature when long limb bones are present. Standard error of estimates reported for fragmented femora, were higher than those given for the metacarpals (Simmons et al. 1990). This led Meadows and Jantz (1992) to conclude that metacarpals are preferred to long bone fragments when estimating stature. Grieshaber (2001) stated that standard errors using metacarpals to estimate stature is higher than from long bones.

3.2.4 Methods used in estimating stature

The ideal stature to measure is that of a living individual. This is more useful than measuring skeletal or cadaveric stature, as it records the actual height of the living individual. Stature recorded on a drivers license (forensic stature), is one piece of information that contributes to data which can identify a living individual. However, its accuracy has been questioned (Ousley 1995). Willey and Falsetti (1991) showed that the heights recorded in a drivers license does not differ significantly from the measured heights. On the other hand, these authors suggested that the height in a driver’s license is not accurate, as it is not updated on a regular basis to account for subsequent growth changes. Giles and Hutchinson (1991) compared measured stature to self-reported stature and found that taller people often overestimate their stature. From these studies, Giles and Hutchinson concluded that forensic stature was not a precise measure. Numerous other studies have reported similar findings (Snow & Williams 1971, Musgrave & Harneja 1978, Sjøvold 2000).

In the forensic context, however, reconstructing stature from human remains is not easy when compared to that of living stature. Forensic anthropologists are often involved in excavation of human remains from graves (Ta'ala *et al*. 2006). Irrespective of the trials and errors in methods used in estimating living or ante-mortem stature, this characteristic trait forms an intergral component in the analyses of unknown individuals. When human remains are found by the police, the task of the forensic anthropologist is to measure the long bones and apply it to linear regression equations. These equations, which are population specific, are developed to estimate stature from known living or cadaver stature. The estimated stature is then compared to recorded as well as reported stature of missing individuals. Estimates of living stature together with characteristics such as age, sex and race, is then used to draw up a profile of the unknown individual (Krogman & İşcan 1986).

A method for estimating stature, using a complete skeleton, was first introduced by Dwight in 1894 (Ryan & Bidmos 2007). This first attempt was improved upon by Fully's method, commonly referred to as Fully's anatomical method .Fully's technique (1956), involves calculating total skeletal height (TSH) from the sum of the following parts of the skeleton, namely, basibregmatic height of the skull, C2 to S1 vertebral body heights, femoral length, tibial length, articulated talo-calcaneal height. Fully's method also incorporates a correction factor for soft tissues in males and females, which is included in calculating total skeletal height. This method brings estimated stature very close to that of living stature. The disadvantage of this technique, however, is that it is time consuming and requires a complete skeleton which is not always available in forensic cases.

Various other methods for estimating stature have been devised by forensic anthropologists. Some of the earlier research in this field includes the work carried out by Trotter and Gleser (1951, 1952) and Trotter (1970). These authors devised regression formulae for estimating stature which were based on data from World War II male casualties of African American and Euro American descent. These authors measured living stature as well as long bone lengths from skeletonized remains. Trotter and Gleser (1958) re-evaluated their original formulae using casualties from the Korean War. This sample contained a more ethnically diverse group of individuals. A number of problems were still encountered with the measured statures reported by Trotter and Gleser including the fact that their formulae were population specific (Jantz *et al*. 1994).

Some authors have used a number of methods to estimate stature in the same sample. For example, Konigsberg *et al*. (1998) compared five different methods, namely, regression stature on a long bone length, regressing long bone length on stature, major axis regression of stature on long bone length, reduced major axis regression of stature on long bone length and the ratio of long bone to stature. According to Komar and Buikstra (2008), regression of stature on long bone length is the method of choice if these remains are from the same "stature distribution as the reference sample" (p. 149). If this assumption cannot be made with certainty, then it is preferable to regress long bone length to stature. Various computer programs provide different combinations of long bone measurements in order to assist forensic anthropologists in estimating stature (Ubelaker 1998).

The aim of devising regression equations is that it should enable the researcher to predict with a certain degree of accuracy the stature of a deceased individual, or to at least estimate stature from the skeletal remains in a forensic case. Some studies have restricted stature estimation to simple percentages while others have used the least squares method of factor analysis to calculate regression formulae (Steele & McKern 1969). Numerous sets of regression equations have been developed and these have been revised for different samples (Trotter & Gleser 1952, 1958, Trotter 1970). Not only has regression equations been used across populations but they have also been employed in prehistoric studies, as discussed earlier on, with poor results (Trotter & Gleser 1958).

Statistical errors than can occur during stature estimation is said to be as much as 10 cm (Mysorekar *et al*. 1980). On the other hand, it has been suggested that a 1 mm difference in the measurement of the total length of a long bone, should not affect the regression equation employed (Mysorekar *et al*. 1984).

Fully's revised anatomical method was incorporated into a study carried out by Raxter *et al*. (2006) whose findings resulted in 95 percent of their samples being correctly estimated to within 4.5 cm. Furthermore, these authors emphasized consistency when carrying out any measurements on bones. They also concluded that the mathematical method was not able to account for disproportionate individuals when compared to the anatomical method. These authors also proposed new formulae for soft tissue value additions.

3.2.5 Effect of age on stature

The height of an individual, irrespective of race and sex, is at its maximum at the age of 21 years (Trotter & Gleser 1951). Thereafter, the height decreases notably after 30 years (Trotter & Gleser 1951), 35 years (Boas 1940) or 40 years according to Büchi (Trotter & Gleser 1951). This reduction in length is said to be as much as 0.06 cm (Trotter & Gleser 1951) or 1cm per year over the age of 50 (Galloway 1988, Himes & Roche 1982). Galloway (1988) was confident that age was the overriding parameter in estimating stature and that the major decline in stature according to him did not begin until the age of 45 years after which the rate of loss in stature was then very rapid. Giles and Hutchinson (1991) suggest a decrease in stature of Americans in their midforties, which in males is 1 mm per year compared to 1.25 mm per year for females.

Statistical analyses carried out by Pearson (1899) proved that shrinkage of bones with ageing does not appear to alter the correlation. Studies in 1951 (Trotter & Gleser) proved otherwise. Negative correlations between stature and age, and in some cases between bone length and age, were reported to occur. Regression formulae which were devised by Trotter and Gleser (1951), adjusted for the effects of aging on stature. The only problem with the proposed formulae is that the sample recorded height of a young military group and did not include those of older individuals.

Friedlander *et al*. (1977) reported that a reduction in stature, associated with an increase in age, is brought about primarily by changes in the vertebral column. In 2006, Raxter *et al*. attempted to address the issue of age correction of stature in their skeletal sample aged between 21 to 85 years. In their observations, these authors noted changes within the individual vertebrae which they incorporated into the anatomical technique of Fully. These authors also reported an age adjustment of 0.04 cm per year in comparison to the 0.06 cm per year recommended by Trotter and Gleser (1951, 1952). The adjustment of age proposed by Trotter and Gleser (1951, 1952) has been questioned by a number of authors (Galloway 1988, Cline *et al*. 1989, Chandler & Bock 1991, Giles 1991). The debate reigns on the fact that firstly, age reduction is nonlinear and secondly, that a decline of stature in males and females follows different patterns. Thus, a gradual loss in height during the fourth decade would be difficult to identify without long term longitudinal data. Melton and Cooper (2001) reported greater height loss in females than in males which predisposes them to vertebral fractures.

Due to anatomical variations in individuals, the age at death is always given as a range (Bass 1995). In order to overcome these problems in forensics, Raxter *et al*. (2006) devised regression equations for estimating living stature from skeletal height which excluded the age correction factor. This adjustment was done so that their equations would be applicable to forensic cases. Furthermore, their study produced slightly lower correlations and higher standard errors of estimates when compared to the results where the age correction factor was included.

3.2.6 Living stature versus cadaver stature

The height of a human being is a measure of how tall or short a person is and this can be defined from a forensic (drivers licence) or biological (cadaver or living individuals) perspective (Ousley 1995). Living stature is measured in the living person, while cadaver stature is measured directly from an embalmed body. The outcome of measuring cadaver stature is to ultimately reach an estimate of living stature. Methods employed to derive at living stature thus differs which may also bring about certain advantages and disadvantage with each method used.

One example is that of reported heights in living individuals. This method is commonly used as it is easy to guess how tall or short a person is.The disvadantage is that forensic anthropologists need accurate information for identification purposes. Reports on living stature in black, coloured and white South Africans of both sexes were provided by Steyn and Smith in 2007. Their measurements were based on the definition of ISO 7250. They recorded the vertical distance from the standing surface to the highest point of the head (vertex) with their subjects in the erect standing position. These authors classified their subjects as short (for results in the lower 25% of stature distribution), tall (upper 25% of stature distribution) and average or medium in height (middle 50% of stature distribution). These authors proposed that their fndings for estimating ante-mortem stature in South Africans be included in forensic reports.

Methods used on cadavers also differ. Some authors have measured hanging stature while others have recorded supine stature on cadavers in an attempt to accurately record stature. Byers *et al*. (1989) used a correction factor devised by Trotter and Gleser (1951) to account for differences between hanging cadaver stature and living stature. A correction factor is necessary as hanging stature is said to be 2.5 cm greater than living stature (Trotter & Gleser 1951).

According to Dupertuis and Hadden (1951) very little difference occurs between supine cadaver stature and living stature to warrant the use of a correction factor. They applied their formula to a cadaver sample belonging to American negroid and white groups, whereby standing statures of cadavers were measured with ice tongs inserted into the ear holes and the bodies suspended so that the soles of the feet were in contact with the ground (Dupertuis & Hadden 1951). Such methods have been criticized as they do not reflect the true stature of these cadavers. Various authors have shown that measurements of living stature as opposed to that recorded on cadavers differ by as much as two and a half centimeters (Telkka 1962, Trotter & Gleser 1952).

In conclusion, while discrepancies in methods used to record living and cadaver stature are known to occur, the heights of cadavers kept in records at medical schools also needs to be checked as it may lead to biased results. This was the case in the present study where cadaver heights were found to be inaccurate or missing and could thus not be used for stature estimation. This resulted in the indirect approach of stature estimation being adopted.

3.2.7 South African studies

Numerous studies on estimating stature have been initiated in South Africa (Lundy 1983, 1985, 1988a, Lundy & Feldesman 1987, İşcan & Steyn 1999, Dayal 2002, Bidmos & Asala 2004, Bidmos 2006, Chibba & Bidmos 2007, Steyn & Smith 2007, Ryan & Bidmos 2007, Bidmos 2008). The earliest recordings of stature in the Southern African population, according to Tobias (1972), goes back to 1910, where unpublished data by Dr WH Brodie was taken over by Dr GA Turner who added to the original data. At this stage, no regression formulae for samples from the African continent were available. In 1983, Lundy devised, for the first time, regression equations for estimating living stature from long limb bones in the South African “Negro”. His sample comprised 177 male and 125 female South African “Negroes” between the ages of 18 and 65 years. His sample was obtained from the Raymond Dart Collection of Human Skeletons, housed at the University of the Witwatersrand. As living stature and cadaver lengths of his samples were not known, Lundy used the anatomical method described by Fully in 1956, to estimate total skeletal height. Once he had calculated the skeletal height using the humerus, radius, ulna, femur, tibia and spine, a correction factor was added for the soft tissues. He added 10 cm for heights of 153.3 or less, 10.5 cm for heights ranging between 153.6 to 165.4 cm and 11.5 cm for heights of 165.5 cm and above. For individuals over 60 years, 0.06 cm was subtracted for every year over the age of 30 years.

In 1987, Lundy and Feldesman revised Lundy’s regresson equations which were published in 1983 due to five cases, which were excluded from the original study, being accidently included in the calculations. Lundy and Feldesman used Fully’s original anatomical technique protocol of 1983, in re-computing skeletal height and lengths of the humerus, radius, ulna, femur, tibia and fibula.The revised results yielded higher correlations with lower standard errors than those reported in 1983. Comparison of results given for the final computed living stature and actual living stature showed a difference of approximately 2.0 cm. Lundy and Feldesman listed the femur as the best single bone to estimate stature in males and females. The best predictor using a number of bones in their study was the combined lengths of the femur, tibia and lumbar vertebral segment. These results were similar to that reported by

Lundy in 1983. The research carried out by Lundy and Feldesman, prompted further studies on stature estimation in the South African population.

To estimate stature in a South African white population, Dayal *et al*. (2008) calculated total skeletal height on a sample of 169 skeletons (98 males and 71 females) using Fully's anatomical method (Fully 1956, Lundy 1985). To obtain regression formulae for total skeletal height, Dayal *et al*. (2008) recorded maximum lengths of the humerus, radius, ulna, fibula, femur (physiological length) and tibia (non-malleolar length). Correlation values of 0.92 for males and 0.93 for females were reported. All lower limb bone correlations were higher in females than in males. Correlation values for the upper limbs in females were shown to be equal or slightly less than those for males. Dayal *et al*. (2008) concluded that lower standard error of estimates was seen in males when compared to females as well as with multivariate (combination of bones)

Bidmos and Asala (2005) used calcaneal measurements to estimate stature in South African blacks using the anatomical method devised by Fully (1956) for deriving regression equations. These authors reported the middle breadth as the variable with the highest correlation value of 0.47. Their highest correlations for the sexes were reported as 0.52 and 0.65 for males and females respectively.

Using the calcaneus to reconstruct adult stature in South Africans of European descent, Bidmos (2006) indicated that correlation values were significantly higher ($p<0.05$) in males than in females. Correlations for combined variables in the sexes were 0.76 for males and 0.79 for females while maximum length had the highest correlation (0.75). The results on the calcaneus for the two South African population groups indicate that the correlation values for whites are higher than for blacks.

Chibba and Bidmos (2007) derived regression equations for estimation of stature and maximum tibial length from six measurements of different fragments of the tibia in South Africans of European descent. These authors found that in males, the highest correlation for an individual variable was obtained for proximal breadth (0.58) and for females it was distal breadth (0.54). Their correlation values, when using various combinations of variables, ranged from 0.58 to 0.61 for males and in females from 0.54 to 0.70. Standard error of estimates for their regression equations in males had values ranging between 6.52 and 6.71 cm and in females they reported a range from 5.20 to 5.94 cm. Their derived regression equations for predicting total skeletal height in females presented with greater accuracies than for males.

The skull has also been used in reconstructing skeletal height in an indigenous South African sample by Ryan and Bidmos (2007). These authors took six measurements of which the basibregmatic height in males showed the highest correlation (0.360) to total skeletal height. In females, the variable selected with the highest correlation with total skeletal height was the maximum bizygomatic breadth (0.606). These authors reported higher correlations for combinations of measurements rather than for individual variable measurements.

Regresssion equations using metatarsals have also been devised for South Africans of European descent and indigenous population groups (Bidmos 2008). Total skeletal height measurements for this sample were calculated according to that described by Fully and Brauer (cited in Bidmos 2008). The number of variables which Bidmos used for the metatarsals included six linear measurements to estimate stature for forensic purposes. These variables were listed as the lengths of metarsals one to four. For the fifth metatarsal, Bidmos recorded the functional and morphological lengths. The highest correlation values for individual variables reported by Bidmos for the indigenous groups were 0.62 for males (metacarpal one) and 0.72 for females (metacarpal one and two). His highest correlation results, for a combination of measurements in the indigenous groups, were recorded as 0.72 in males (all six variables) and 0.76 for females (a combination of firstly, metacarpals one, three and physiological length of the fifth metacarpal and secondly, for metacarpals one, two, three and physiological length of the fifth metacarpal). For the group of European descent, the highest correlation values were reported by Bidmos as 0.72 for males (firstly, metacarpals two, four and both physiological and functional lengths of the fifth metacarpal and secondly, all six variables together) and 0.76 for females (a combination firstly of metacarpals one, two and functional length of the fifth metacarpal and secondly, metacarpals one, two and both length measurements of the fifth metacarpal). Males were shown to consistently have higher mean values when compared to females (p<0.0001) for total skeletal height.

Fragmentary femora have been successfully used to reconstruct stature in South Africans both of European descent and indigenous South Africans (Bidmos 2008). The seven femoral measurements which Bidmos undertook, included the maximum length, upper epicondylar length, vertical neck diameter, epicondylar breadth, bicondylar breadth, medial and lateral condylar length. These measurements were recorded according to definitions given by Bräuer (cited in Bidmos 2008). In males, the upper epicondylar length displayed the highest correlation (0.661) with total skeletal height and the epicondylar breadth the lowest correlation (0.525). In females, the highest and lowest correlations to total skeletal height were the lateral condylar length (0.729) and upper epicondylar length as well as vertical neck diameter (0.562) respectively. Bidmos reported slightly lower correlation values between maximum femoral length and fragmentary femoral measurements. For males, the highest and lowest correlations were given as 0.610 (upper epicondylar length) and 0.400 (epicondylar breadth respectively. For females, Bidmos obtained values of 0.781 (bicondylar breadth) and 0.544 (vertical neck diameter) as the highest and lowest correlations. Generally, Bidmos found the mean values to be significantly higher (p<0.0001) in males than in females.

In conclusion it can thus be said that there are South African standards for regressions from whole long limb bones for both black (Lundy & Feldesman 1987) and white (Dayal *et al.* 2008) groups, as well for fragmented tibia and femora, but nohing currently on hand bones for this population.

CHAPTER 4

LITERATURE REVIEW - SEX DETERMINATION

4.1 Introduction

When forensic anthropologists are confronted with decomposed material which is human in nature, great consideration is placed on anatomical detail in order to compile the morphological data of an individual (Rich *et al.* 2005). Together with the determination of age, population affinity, and stature, the establishment of sex from the analysis of human skeletal remains is of vital importance in forensic identification (Krogman & İşcan 1986, Rich *et al.* 2005).

The genetic, morphological and biological difference between males and females of the same species is referred to as sexual dimorphism. These genetic and physiologic differences are extremely marked which makes it possible to establish the sex from the human skeleton (Holman & Bennet 1991, Bass 1995, White & Folkens 2000). The extent to which the human skeleton, or parts thereof, can be used to determine sex with a fair degree of accuracy is of importance to physical anthropologists and forensic scientists (Thieme & Schull 1957).

Sexual dimorphism of the human skeleton has been well documented, with some regions described in greater detail and receiving more attention than others. According to Williams *et al.* (1989), the preference of using a bone relates to its anatomical position in the skeleton and subsequently to its functional role in males and females.

The bones of the skeleton commonly used to establish sexual dimorphism, include the pelvis, skull and long bones, which have been studied either on their own or in combination with other bones. Williams *et al.* (1989) have shown that because the axial skeleton is relatively heavier in males than in females, it creates a force which is carried over to the femur, motivating the use of this bone in comparison to other long limb bones to distinguish between the sexes.

To sex the remains of an unknown adult individual is easier than that of the neonate or juvenile, except in cases where the adult skeleton is incomplete, which makes the task more daunting and difficult. Working with an intact skeleton, which is the ideal for any researcher, it is possible to obtain ±100 % accuracy in establishing the unknown individual's sex (Krogman & İşcan 1986).

However, skeletal remains may be found poorly preserved and fragmented rather than well preserved and intact (Franklin *et al*. 2008). In practice, the common methods employed by physical anthropologists and forensic scientists are either non-metric (visual of morphological) or metric in nature.

Sex determination based on differences in skeletal morphology has been successfully carried out on the pelvis (Krogman & İşcan 1986), skull (De Villiers 1968, Krogman & İşcan 1986), scapula and humerus (Steele 1970) and, mandible (Loth & Henneberg 1996). These morphological studies have also shown that males tend to be larger and more robust than females (De Villiers 1968, Loth & İşcan 2000). While morphological indicators are useful with intact bones, their value and accuracy is reduced when only bone fragments or an incomplete skeleton is available. This has led to the development of standards for metric sex determination of various parts of the skeleton. In cases where forensic findings need to be defended in court, the accuracy of sexing an unknown individual is often coupled to the metric methods employed in such an investigation.

The earliest recording of the use of metric methods was by Washburn in 1948. He measured lengths of the ischium and pubis and calculated an ischio-pubic index from these bones. From this study, Washburn reported sexing accuracies of 90%.

In 1955, the first assessment of long bones was carried out by Pons, who developed discriminant function formulae for femora and sterna obtained from a skeletal collection in Lisbon. In 1957, Thieme and Schull used several long bone variables on an African American sample taken from the Terry Collection. Their results showed that the maximum length and bicondylar width of the humerus were the best variables to use in assigning sex. They aso reported higher accuracies with a combination of bones when compared to the use of single bones. Standard osteometric methods have since been widely used by numerous authors in assessing and determining sexual dimorphism (Black 1978, Novotny *et al*. 1993, France 1998, Asala 2001).

Invariably, from a series of measurements recorded on a bone, it may be that one variable is singled out as providing the highest degree of accuracy when establishing sexual dimorphism (Black 1978). This has been shown in the case, for example, where the pubic length has been preferred over and above the ischial length (Washburn 1948, 1949, Hanna & Washburn 1953).

4.2 Literature review

The purpose of this section is to review past and present research directly associated with the use of various aspects of the skeleton in establishing sex as a form of identification. As the literature is so vast, particular emphasis will be placed on previous studies involving the hand, as well as studies on sexual dimorphism in South Africa.

4.2.1 Manifestation of sexual dimorphism in the skeleton

Scientists have attempted to incorporate almost all of the bones of the postcranial skeleton in their investigations on sexual dimorphism (Krogman 1962). Intact and complete skeletons are not always available resulting in studies being carried out on single bones or fragments thereof that have been obtained from excavation expeditions, or from recovered bodies in forensic cases.

The bones of the skeleton receiving a great amount of attention includes the humerus (e.g., Singh & Singh 1972a), radius (e.g., Steel 1963), ulna (e.g., Steel,1963, Singh & Singh 1974), clavicle (e.g., Thieme & Schull 1957, Jit & Singh 1956), sternum (e.g., Thieme & Schull 1957, Jit *et al.*1980), scapula (e.g., Bainbridge & Genoves 1956), pelvis (e.g., Reynolds 1947, Washburn 1948, Kelly 1978, Weaver 1980, Kimura 1982a), sacrum (e.g., Flander 1978, Kimura 1982b, İşcan & Derrick 1984), femur (e.g., Dwight 1905, Pearson 1917-1919, Steel 1963, Singh & Singh 1972b, Black 1978, DiBennardo & Taylor 1979, 1982, İşcan & Miller-

Shaivitz 1984a, Dittrick & Suchey 1986, Steyn & İşcan 1997), tibia (e.g., Dwight 1905, Steel 1963, Singh 1975, İşcan & Miller-Shaivitz 1984b, 1984c; Kieser *et al.* 1992, Steyn & İşcan 1997) and fibula (e.g., Steel 1963, Singh & Singh 1976). These bones have been shown to be accurate predictors in determining sex. In other words, these major long bones have been preferred over other ones. While weight-bearing bones of the skeleton are preferred in studies on sexual dimorphism, non-weight bearing bones can also be sexually dimorphic (MacLaughlin & Bruce 1985).

The impact of the forces received by the pelvis to the femur has resulted in this bone being used extensively in various populations, including the Japanese (Hanihara 1958), Australian aborigines (Davivongs 1963), American blacks, whites, and Indians (Black 1978, DiBennardo & Taylor 1979, 1982, İşcan & Miller-Shaivitz 1984c, 1986), Italians (Pettener 1979), Czechs (Cerny & Komenda 1980), prehistoric Scottish (MacLaughlin & Bruce 1985), Chinese (İşcan & Shihai 1995), and Nigerians (Asala 1998). These studies are all based on an intact femur rather than fragments of the bone.

4.2.2 Manifestation of sexual dimorphism in bones of the human hand

In adults, sexual differences are evident in hand length measurements and in hand width to length ratios (McFadden & Shubel 2002). Observations of the index and ring finger indicate that the second digit in males is shorter than the fourth digit while in females they are either of equal length or it may be that the second digit is slightly longer than the fourth one. In young adults, sexual dimorphism in the diaphyseal diameter of metacarpals appears to be related to differences in body size (Himes & Malina 1977). In other words, at a constant body size and age, diaphyseal measurements of the metacarpals in males are shown to be significantly larger than that in females (Himes & Malina 1977).

With an increase in age, the metacarpals are reported to reduce in size, a feature more prevalent in males than in females (Harris *et al.* 1992). Bone loss in second metacarpals occurs more rapidly in females than in males especially after the fifth decade and then tends to decrease after the sixth decade (Plato & Purifoy 1982). The midshaft of second metacarpals is particularly prone to earlier bone loss than the rest of the bone, an observation that is age-related (Kimura 1990, Lazenby 1998). The rate of bone loss probably relates to the amount of cortical bone present. Earlier studies have concluded that in males the second metacarpal was longer and composed of more cortical bone than in females (Plato *et al*. 1982).

The weight of an individual is known to place a load on the skeleton which ultimately accounts for sexual differences recorded in the pelvis and lower limb (McFadden & Shubel 2002). It may be assumed that if similar forces were placed on the hands, that these sexual differences may be expressed in the individual bones of the human hand. Research in hominids has shown that the relatively large distal phalanges are due to these bones accommodating increased loads (Smith 1995). On the other hand, there is evidence to indicate that distal phalanges have decreased rather than increased in relative size through time (Smith 1995). This reduction in size has been ascribed to negative selective forces (Smith 2005).

External factors such as culture and environment are also known to have an influence on sexual differences in the human skeleton (Loth & İşcan 2000). The hands are no exception to this influence. In the late 1900's it was shown that metacarpals are poorly preserved and relatively small in size when compared to long bones. For this reason, metacarpals were excluded from studies on sexual dimorphism (Black 1978). Other studies, however, have shown the hands to be as sexually dimorphic as the rest of the skeleton (Garn *et al*. 1973, Meadows & Jantz 1992). In fact, the second metacarpal has contributed to methodologies in forensic anthropology with regard to identification of the sex of an individual. (Falsetti 1995, Scheuer & Elkington 1993). The relatively large size of the second metacarpal may be due to apposition of bone on the outside rather than resorption from the medullary area which influences the width of the second metacarpal (Plato *et al*. 1980).

Scheuer and Elkington (1993) in their cadaveric study of sex differences on metacarpals and first proximal phalanx of 60 white British subjects, described a multiple regression method which yielded accuracies of 74% to 94% with the first metacarpal showing the highest degree of accuracy. They employed combinations of six measurements for each metacarpal in order to generate multiple regression equations (Scheuer & Elkington 1993).

According to these authors, a method used to sex the bones is only useful if it yields an accuracy of at least 80%.

Falsetti (1995) used the data collected by Musgrave in 1970 on the metacarpals of a cadaveric sample at the Royal Free Medical School in London. To this sample he added metacarpals of 212 individuals from the Terry collection at the Smithsonian Institution in Washington and increased his sample with an additional 40 cases from the forensic or donated collection in the Maxwell Museum of Anthropology in New Mexico. Falsetti (1995) used 5 measurements for each metacarpal to generate discriminant functions. Data for the different populations were pooled, so too were the measurements for right and left metacarpals. His results on the collections yielded accuracies of 78.0% to 92% for the second metacarpal, 80.0% to 86% for the fourth metacarpal, and 84.0% to 85.0% for the fifth metacarpal. Furthermore, he concluded that metacarpals 1 and 3 exhibit different levels of sexual dimorphism and great variation in morphology by race and could not be used to develop discriminant functions. Falsetti (1995) also tested for population differences and found that metacarpals 2, 4 and 5 displayed no morphological differences that were population specific.

Wien (1984) was able to show that length and width measurements of metacarpals and phalanges were approximately 90.0% accurate in detecting sexual differences. Scheuer and Elkington (1993) generated their prediction accuracy for correct sex determination which ranged from 78.0% to 94.0% for the metacarpals. In 2003, Burrows *et al.*, rather than devising their own regression formulae, tested equations already developed for different populations groups. They concluded that the percentage accuracies are for the same for all the metacarpals. While some studies prove that metacarpal one is the most accurate in sexing individuals (Scheuer and Elkington 1993), the same bone was found to be the least accurate in another study (Burrows *et al.* 2003). In some cases, authors may report on the same bone as providing the highest accuracies as is the case with the second metacarpal (Falsetti 1995, Burrows *et al.* 2003).

Stojanowski (1999) placed the 4th metacarpal top of his list. What these findings show is that these equations cannot be used across populations as these studies indicate that different hand bones show different prediction accuracies. Smith (1996) also used the osteological collections incorporating metacarpals and phalanges in order to correctly sex and population affinity. In hand studies most of the focus has been on the use of metacarpals (Scheuer & Elkington 1993, Smith 1996) however, this has changed to include the proximal and distal phalanges as well (Smith 1996, Scheuer & Elkington 1993).

Using metacarpals, Scheuer and Elkington (1993) reported an overall sexing accuracy ranging from 74.0% to 94.0% with the first metacarpal producing the highest degree of correct estimation. Lazenby (1994) reported sexing accuracies ranging from 97.4% to100% for males and 37.5% to 76.8% for females using the right and left second metacarpal. The average sexing accuracy for his total sample was 94.0%. Lazenby concluded that the right second metacarpal was more likely to provide correct identification in males while in females it was the left side.

Smith (1996) reported results for both right and left hands ranging from 87.0% to 89.0% for metacarpals, 76.0% to 79.0% for proximal phalanges, and 81.0% to 83.0% for distal phalanges. Results for the middle phalanges were slightly different in that the left hand yielded average results of 79.0% while the right hand yielded results of 72.0% while another three pairs of models yielded success rates of 2-3%. Smith applied her models for sex determination in reverse and reported success rates of 84-86% for metacarpals. Of all the metacarpals, the second (Kusec *et al.*1988, 1989, Plato 1980), third and fourth metacarpals have received most of the attention (Kusec *et al.* 1988, 1989).

In conclusion, the literature indicates that the hand bone with the highest degree of accuracy differs for each population group. While Thieme and Schull (1957) emphasized the fact that right-left asymmetry has no value when estimating sex, current research clearly indicates that right-left asymmetry does contribute to the sexing process.

4.2.3 Sexual dimorphism in the South African population

While forensic anthropology is known to be one of the fastest growing fields worldwide (İşcan 1988), South Africa, which is located in an interesting geographical part of the world, may slowly be included in this category in the near future. Its unique position at the tip of Africa has provided opportunities for different populations not only from Africa, but also from the rest of the world to converge and exchange genes. One may assume that the South African population has over the centuries, and with its history, been composed of a gene flow representative from every part of the world (Benjeddou 2006). Besides estimating factors such as race, age and stature, South African forensic anthropologists have also included determination of sex in the identification of unknown remains.

The earliest studies on sexual dimorphism in South Africa were reported by de Villiers (1968) who studied the skulls of the South African black population. This author collected non-metric and linear metric data to establish sexual dimorphism, however, no discriminant function equations were devised for this sample. Later research has seen the development of discriminant equations which has resulted in a considerable surge in the number of standards available for estimating sex in the South African population. Rightmire (1972) reported sexing accuracies using the crania of South African blacks as 90.6%. Franklin *et al.* (2005a, b) also examined crania from indigenous South African groups in order to establish sexual dimorphism. They reported accuracies ranging between 77.0 - 80.0% and listed the facial width as the most accurate trait followed by the cranial length and basi-bregmatic height. Steyn and İşcan (1998) reported sexing accuracies for the cranium in South African whites as 86.0%.

The bones of the feet have not been excluded from such studies. Bidmos and Asala used the calcaneus to discriminate sex in South African whites (2003) and blacks (2004). Mean values for their male sample were significantly higher ($p<0.001$) than for the female sample in both groups. For their white sample the variable with the highest percentage accuracy in the stepwise (91.1%) and direct discriminant (92.1%) analyses was the dorsal articular facet breadth. In testing the validity of the discriminant function equations, Bidmos and Asala reported that 88.0% of their sample was correctly sexed using the stepwise analysis while the direct analysis of all their variables computed an 84.0% accuracy of correct classification. Their findings for the black group showed that the dorsal articular facet length, presented with the highest percentage accuracy using the demarking process (79.3%) and stepwise analysis (85.3%). Maximum height of the calcaneus was the variable with the highest percentage accuracy (86.2%) in the direct analysis. The percentage of cases correctly classified and cross-validated ranged between 79.3 - to 86.2% for the direct analysis and 79.3 - 85.3% for the stepwise analysis. When compared to the results of the white group, those of their black group had slightly lower average percentage accuracies. Bidmos and Asala concluded that measurements of breadth and length are of greater value than height as sex determinants when using the calcaneus.

Bidmos and Dayal used the talus to establish sexual dimorphism in South African whites (2003) and blacks (2004). Their mean values indicated statistically significant differences ($p<0.05$ for whites and $p<0.001$ for blacks) between males and females. High correlation coefficients ranging from 0.90 to 0.99 were also reported by these authors for both groups. Sexing accuracies for their white group, as computed from the direct analysis were given as 82.0% (talar length) and 80.0% (breadth of the posterior auricular surface). Results for the stepwise analysis indicated that talar length had the highest sexing accuracy of 87.5% (all variables entered) and 85.0% (for all lengths entered) while the breadth of the trochlea had the highest sexing accuracy of 77.5% (for all breadth dimensions entered). The average sexing accuracy for lengths was given as 88.0% as compared to average breadth accuracy of 78.0%. Sexing accuracies for their black sample which was based on the direct analysis, listed the talus head as the variable with the highest average sexing accuracy (85.8%). In their stepwise analysis the average sexing accuracy was 86.7% with an overall length and breadth accuracy of 85.0% and 84.2% respectively. These authors concluded that the talus length for whites and talus head for blacks were the best sex discriminators.

In establishing standard numerical values and demarking points to determine sexual dimorphism, Asala (2001) used the femoral head obtained from a South African white and black skeletal sample. This author established that there were no statistically significant side differences in the vertical and transverse head diameters in both sexes for whites and blacks. On the other hand, the same parameters were found to be significantly higher ($p<0.001$) in males than in females for both groups. A comparison of the two groups showed that the identification and demarking points in South African whites are higher than in their black counterparts. Asala concluded that the mean head diameter of right and left femora or only the vertical head diameter can be used to establish sex in this population if only a fragment of this bone is available.

Based on his findings in 2001, Asala then looked at the efficiency of the demarking point of the transverse and vertical femoral head diameters as parameters to determine sex (2002). For the white group, this author reported 32.0% cases for three vertical diameters and 18.0% for three transverse diameters that could be accurately sexed using the demarking points. A comparison of the sexes indicated that only 47.0% males and 18.0% females could be accurately sexed. In total, 32.0% of his cases could be accurately sexed using the demarking. For his black sample, Asala reported sexing accuracyof 22.0% (using the vertical diameter) and 31.0% (using the horizontal diameter) when combining the demarking points for right and left sides. The demarking point could also be used to accurately sex 47.0% males and 10.0% females. This author concluded that the overall success rate using the demarking point in South African blacks was the same as for whites, namely, 32.0%.

Fragments of the femur of a South African black population have also been shown to be sexually dimorphic (Asala *et al*. 2004). Percentage accuracies reported by Asala *et al* (2004) for the proximal femoral end ranged between 85.1 - 82.6% compared to 85.1 – 82.6% at the distal end for combined and single variables respectively. These authors concluded that the femoral head was the most important sex discriminator in this population group. Contrary to these findings, Steyn and İşcan (1998) stated that the distal femoral breadth was the best variable selected to discriminate for sex in the South African white population group.

Steyn and İşcan (1997) studied the femur and tibia in South African whites and reported average accuracies ranging from 86 – 91%. Their results for classification accuracy on the humerus in South Africans (1999) were 96.0% (whites) and 95.0% (blacks) which was slightly higher than their earlier study on lower limb bones but nonetheless high. Generally, their accuracies for females were slightly higher than for their male samples except in the case of the humerus where accuracies for black males (95.0%) were slightly higher than black females (91.0%). These authors concluded that in the humerus, the head and epicondylar diameters in whites and head and maximum length dimensions in blacks as the best discriminators of sex. Kieser *et al*. (1992) reported classification accuracies using the proximal tibial end as ranging between 84.6 - 92.0% for white and black South Africans, results which are similar to that given by Steyn and İşcan (1997).

Franklin *et al*. (2008) used seven standard and two non-standard dimensions of the mandible to establish sexual dimorphism in five (Zulu, Swazi, Xhosa, Sotho and Tswana) local black South African populations. These authors found very little variation in sexing accuracies between the five local population groups and presented results for a pooled sample. Results from their F-statistics analysis, listed four variables that expressed the greatest level of dimorphism. These variables, including their expected sexing accuracies, were given as follows: maximum length (77.3%), height of the ramus (73.8%) and coronoid process (73.3%) and bi-gonion beadth (70.7%). Stepwise analyses results for.the pooled groups, indicated the highest percentage (81.8%) recorded was for the coronoid height. The percentage for sexing accuracy, as computed from the direct analysis of the pooled sample, was 84.0%. Steyn and İşcan (1998) showed that the bizygomatic breadth was the most dimorphic of all the measurements taken with an average accuracy of 80.0%, similar to that given by Loth and Henneberg (2001).

While South African studies mentioned thus far report on sexual dimorphism for whites and blacks, pooling of data of the two groups has also been done. One such study is that carried out by Barrier and L'Abbé (2008). These authors used nine anthropometric measurements of the radius and seven of the ulna, to establish sexual dimorphism in a modern South African sample (n=400). Results for the radius indicate that the minimum midshaft diameter was listed as the single best discriminating variable in males (82.0%) and females (86.0%). Classification accuracies in males ranged from 80.0 - to 86.0% for the radius and 76.0 - 87.0% for the ulna. In females, the accuracies reported varied between 82.0 - 88.0% for the radius and 83.0 - 89.0% for the ulna.

A sesamoid bone such as the patella, which is said to display very few post-mortem changes (Introna *et al*. 1998), was used as a sex determinant in South African blacks with results indicating average classification accuracies ranging between 60.0 - 80.0% (Dayal & Bidmos 2005).

Initial studies on South Africans reported on different groups such as the Zulu, Xhosa and Southern Sotho populations while more current research in the field of sexual dimorphism publish results purely on the South African white and black population group. This is due to the fact that the earlier groups are disappearing (Franklin *et al.* 2006).

It can be concluded that while earlier studies carried out on South Africans presented with numerous problems due to the diverse ethnic origins and mixture of the various populations which occured as a result of urban migration, current research focuses on the South African white and black population groups. Furthermore, diagnostic accuracies for the crania are far less when compared to that obtained from the femur and tibia in the South Africans (Steyn & İşcan 1998). While attempts are made to establish discriminant function equations for various aspects of the skeleton for South Africans, a comprehensive analysis of sexual dimorphism in the hand bones of this population group is lacking.