DEVELOPING SOFT TISSUE THICKNESS VALUES FOR SOUTH AFRICAN BLACK FEMALES, AND TESTING ITS ACCURACY

by

Daniële Cavanagh

Submitted in fulfilment of the requirements for the degree:

MSc. (Anatomy)

In the School of Medicine, Faculty of Health Sciences

University of Pretoria, South Africa

July 2010

© University of Pretoria

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

DECLARATION

I, Daniële Cavanagh, declare that this thesis is my own work. It is being submitted for the degree of Master of Science in Anatomy at the University of Pretoria. It has not been submitted before for any other degree or examination at this or any other university.

____

D. CAVANAGH

This______day of ______________________, 2010

TABLE OF CONTENTS

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ABSTRACT

In forensic science one frequently has to deal with unidentified skeletonised remains. When conventional methods of identification have proven unsuccessful, forensic facial reconstruction (FFR) may be used, often as a last resort, to assist the process. FFR relies on the relationships between the facial features, subcutaneous soft tissues and underlying bony structure of the skull.

The aim of this study was to develop soft tissue thickness (STT) values for South African black females for application to FFR, to compare these values to existing literature or databases, and to test the accuracy and recognisability of reconstructions using these values. It also established whether population-specific STT values are necessary for FRR.

Computerised tomography scanning was used to determine average population-specific STT values at 28 facial landmarks of 154 black females. The Manchester method of facial reconstruction was employed to build faces, for which antemortem photographs were available, on two skulls that were provided by the South African Police Service's (SAPS) Forensic Science Laboratory.

Different data sets of STT values, namely values from this study, two sets of data from American blacks and a South African mixed ancestry group, were used to build four faces for each of the skulls. Two identification sessions were then held. In the first session, 30 observers were asked to select matches from a random group of 20 photographs of black females which included the two actual images. The identification rates calculated for each photograph revealed that the highest rates of a positive match were for the reconstructions based on South African values. In the second session another group of 30 volunteers were asked to match to each photograph the most similar of the four reconstructions made of that particular individual. The reconstructions with STT values from the current (South African) study were selected more often than the other data sets.

Although shortcomings do exist, the identification sessions indicated that FFR can be of value. Furthermore, population-specific STT values are important, since skulls reconstructed using these values were selected or identified statistically significantly more often than the others.

Keywords:

Forensic facial reconstruction

Identification

Skull

Computerised tomography scan measurements

Soft tissue thickness

Database

Population-specific

Variation

Accuracy

Recognisability

ABSTRAK

In forensiese wetenskap het mens dikwels te doen met ongeïdentifiseerde skeletmateriaal. Wanneer die konvensionele metodes van identifikasie onsuksesvol is, mag forensiese gesigsrekonstruksie (FGR) gebruik word, dikwels as `n laaste uitweg, om die proses te help. FGR is afhanklik van die verhouding tussen die gelaatstrekke, subkutane sagte weefsels en onderliggende benige struktuur van die skedel.

Die doel van hierdie studie was om sagte weefsel dikte (SWD) waardes vir Suid-Afrikaanse swart vroue te ontwikkel vir gebruik met FGR, om hierdie waardes te vergelyk met bestaande literatuur of databasisse, en die akkuraatheid en herkenbaarheid van rekonstruksies waar hierdie waardes gebruik was te toets. Dit is gedoen ten einde vas te stel of bevolking-spesifieke SWD waardes nodig is vir FGR.

Gerekenariseerde tomografie skandering is gebruik om die gemiddelde bevolking-spesifieke SWD waardes op 28 gesigslandmerke van 154 swart vroue te bepaal. Die Manchester metode van gesigsrekonstruksie is gebruik om twee skedels, waarvan antemortem foto's beskikbaar was en wat voorsien is deur die Suid Afrikaanse Polisie Diens (SAPD) se Forensiese Wetenskap Laboratorium, op te bou.

Verskeie data stelle vir SWD waardes, naamlik waardes verkry in hierdie studie, twee stelle Amerikaanse waardes vir swart vroue en `n Suid Afrikaanse groep van gemengde afkoms, is vir hierdie studie gebruik om vier gesigte van elk van die skedels te bou. Twee identifikasie sessies is gehou. In die eerste sessie is 30 deelnemers gevra om passende foto's uit `n algemene versameling van 20 foto's van swart vroue te kies. Dit het die twee ware gesigte ingesluit. Die identifikasie waardes wat bereken is vir elke foto het getoon dat die hoogste waardes vir die werklike foto's verkry is op rekonstruksies gebasseer op Suid-Afrikaanse waardes. In die tweede sessie was `n ander groep van 30 vrywillgers gevra om die mees soortgelyke van die vier rekonstruksies by die foto van die betrokke individu te pas. Die rekonstruksies met SWD waardes van die huidige (Suid Afrikaanse) studie was meer dikwels gekies as die van ander data stelle.

Hoewel verskeie tekortkominge bestaan, het die identifikasie sessies getoon dat FGR van waarde kan wees. Verder is bevolking-spesifieke SWD waardes belangrik, aangesien skedels wat opgebou is met hierdie waardes statisties beduidend meer dikwels gekies of geïdentifiseer is as die ander.

Sleutelwoorde:

Forensiese gesigsrekonstruksie

Identifikasie

Skedel

Gerekenariseerde tomografie skandering metings

Sagte weefsel dikte

Databasis

Populasie spesifiek

Variasie

Akkuraatheid

Herkenbaarheid

ACKNOWLEDGEMENTS

I would like to express my gratitude to the South African National Research Foundation (NRF) and Research Committee of the University of Pretoria (NAVKOM) for their support and grants made available for this project.

I would like to thank my supervisor, Prof M Steyn, for her patience, support and guidance throughout this project. Thank you for your enthusiasm and motivation until the very end. I am also grateful to the staff at the Department of Anatomy of the University of Pretoria for their ideas, assistance and constructive criticism at all times throughout the project.

I would also like to thank my co-supervisor, Dr C Wilkinson, at the University of Dundee, Scotland, for her input, guidance and support, especially with the training she provided in the Manchester method of facial reconstruction. I am also grateful to the staff at the University of Dundee for their hospitality and sharing of ideas during my time in Scotland.

Thank you to Louise Euthimiou and the University of Pretoria Postgraduate Study Abroad Bursary Programme for assisting with the funding to visit Scotland so that I could be trained in the Manchester method.

Thank you to Prof Z Lockhat and Prof JL Höll for permission to use CT scans, as well as Ms Erika Smith and staff at the Department of Radiology of the Steve Biko Hospital for their advice and help with the CT scan programme. Also a word of thanks to Ms R Human for assisting with the measurements for inter-observer reliability tests, and to Prof PJ Becker for providing assistance with the statistical analysis of the measurements.

Thank you to all the students who handed in photos for use in the identification sessions, and to the volunteers that participated in these identification sessions as observers.

Special thanks go to Captain TM Briers and Constable E van der Westhuizen from the Facial Reconstruction Unit, at the South African Police Service's Forensic Science Laboratory, for providing the skulls and photographs used in my study, for sharing their knowledge and experience, and for their time, guidance and input throughout the project.

Lastly, I would like to thank my parents, Charles and Elsie Cavanagh, for their continual love and support, and family and friends, especially Mariet, for their interest, thoughts, prayers, inspiration and optimism throughout this project and my studies. Thank you to Tracy for helping with the editing: I appreciate it very much. A special thank you goes to Riaan for giving me strength and hope, for his unconditional support, his brilliant mind, advice, ideas and, most of all, his patience.

LIST OF FIGURES

LIST OF TABLES

"As poles to tents and walls to houses, so are bones to all living creatures, for other features naturally take their form from them and change with them."

- Galen

CHAPTER 1 – INTRODUCTION

1.1 INTRODUCTION

In the field of forensic science, one frequently has to deal with unidentified skeletonised remains, where the challenge is to identify the "unidentifiable" (Burns 2007). Conventional methods such as DNA comparison, craniofacial superimposition or dental record comparison are commonly used to identify the skeletonised remains, but the success of these methods depends on the condition of the remains and requires some comparative material obtained from family members, patient history or a personal item of the missing individual (Burns 2007). However, often it happens that there is no clue towards the identity of the individual (Turner *et al.* 2005, Wilkinson 2005) which makes it impossible to confirm positive identity with any of these methods. In such cases, forensic facial reconstruction (FFR) may be used to assist the process and is therefore often viewed as a last resort to aid with the identification of skeletal remains (Reichs and Craig 1998; Vanezis *et al.* 2000).

FFR is viewed as the scientific art of creating the face on the skull for personal identification (George 1987**;** Miyasaka *et al.* 1995; El-Mehallawi and Soliman 2001; Kim *et al.* 2005). FFR is an attempt to reproduce a likeness of the facial features of a skull, often by a three-dimensional building up of the face, on a skull or a cast thereof, with artistic clay, based on standard soft tissue thickness (STT) values and other anatomy-based rules (Rhine 1984; Aulsebrook *et al.* 1995; Wilkinson 2004; Vandermeulen *et al.* 2006). The goal of these reconstructions is to estimate or approximate the facial appearance of an individual at the time of death (Claes *et al.* 2006) to suggest the identity of the deceased (Aulsebrook

2000). Photographs of the reconstructed faces can be circulated via the media in the hope that they will be recognised (Rhine 1984) by facial features that have a resemblance to a missing or deceased person (Tyrrell *et al.* 1997; Wilkinson 2004). This recognition can then provide a lead towards the identification of the individual, which can be followed up with DNA assessment, medical or dental records or other accepted methods for further comparative analysis towards establishing the identity (Nelson and Michael 1998; Quatrehomme *et al.* 1997; Wilkinson 2005; De Greef *et al.* 2006).

It is important to keep in mind that facial reconstruction is not a method of positive identification (Rhine 1984; George 1987; Wilkinson 2005), but may only aid identification by excluding suspected individuals from investigations (George 1987; Stephan and Henneberg 2001) or by providing a lead by stimulating witnesses' memories to possibly support or bring forth other identifying evidence (Tyrrell *et al.* 1997; Reichs and Craig 1998; Vanezis *et al.* 2000).

Facial reconstruction from the skull is a combination of art and science (Phillips and Smuts 1996; Gatliff and Taylor 2001). Much criticism has been voiced on the accuracy of the techniques used to determine the relationship of certain facial features (e.g. Stephan and Henneberg 2001; Stephan 2003), the accuracy of the reconstruction methods (e.g. Stephan and Henneberg 2001; Stephan 2003), the method of facial reconstruction assessment (e.g. Stephan and Henneberg 2006), as well as on the subjective nature of this practice (e.g. Helmer *et al.* 1993; Wilkinson 2004; Turner *et al.* 2005). It has also frequently been questioned whether the identification rates of reconstructed faces from face pools are above chance (e.g. Stephan and Henneberg 2001; Stephan and Henneberg 2006). However, published rates of successful identifications are generally high (Gatliff and Taylor. 2001; Stephan and Henneberg 2001) and many forensic scientists and artists believe that FFR is of value to be employed in the identification of skeletal remains.

1.2 PROBLEM STATEMENT AND AIMS

Producing a face from the skull relies on a relationship between the soft tissues covering the skull and the underlying bony features. The reproduction of the facial features is based on averages of these soft tissues over various anatomical sites on the skull (Phillips 2001). One of the problems associated with FFR is the reliance on the use of these average facial STT's (Codinha 2009), as well as the difficulty of estimating these values. Many studies are ongoing to add to the database for specific age, sex and population groups, but there is still a lack in studies to establish whether the variation between sexes and ages within and between population groups may or may not be great enough to influence an identification or lack thereof (Manhein *et al.* 2000). A number of studies that have been conducted also contradict each other. Some studies have concluded that body weight plays a role and that notable differences in tissue thicknesses exist between age groups, males and females, as well as people from different ancestral origins (Phillips and Smuts 1996; Manhein *et al.* 2000; Starbuck and Ward 2007; Sahni *et al.* 2008), whereas other studies have concluded that these differences are insignificant or negligible (Stephan and Simpson 2008).

Furthermore, it is also a problem that all published techniques for STT measurement and for FFR are individual techniques used by the forensic artists or anthropologists in their own practices, but a single, official method has not yet been recognised (Reichs and Craig 1998). None of the techniques are without criticism, and all of the techniques are still being investigated or improved, therefore the choice of the measurement or reconstruction method eventually lies with the investigator and his or her team. This further contributes to the inconsistency in STT data and results of the reconstructions.

Facial recognition in itself presents great difficulty as a result of the immense variation in the human face (Roelofse *et al.* 2008), whether due to environmental factors or appearance variability inherent to the face itself (Bronstein *et al.* 2005). People from different continents and of different population groups also vary to a great degree. This human variation has an enormous effect on the creation and representation of a facial reconstruction (Starbuck and Ward 2007) and these issues greatly affect the accuracy thereof (Phillips and Smuts 1996). Consequently, with less accurate reconstructions, the possibility of recognition will be lower. It is therefore necessary to have population-specific standards when it comes to facial identification and reconstruction studies.

To date, many studies have been conducted to establish STT measurements for different groups, and to determine whether the STT of one ancestral group is significantly different from that of another. The question still remains what the influence will be when data from one population group are used to build up faces of another population group (Tedeschi-Oliveira *et al.* 2009), and whether this influence will be of much importance, that is, if it makes any difference to the observer's perception of a finished face (Rhine and Campbell 1980). Still, it makes sense that if one wants a method of producing the likeness of an individual to be effective, the data or measurements should be derived from genetically, geographic or socially related people (Aulsebrook *et al.* 1996).

So far two studies have been conducted on South African population groups, one by Aulsebrook *et al.* (1996) to develop new STT standards for black male Zulus from KwaZulu-Natal, and another similar study by Phillips and Smuts (1996) on a mixed origin population from the Cape Province areas. No standards exist for STT for the reconstruction of South African black female faces and, currently, STT values used are derived from studies conducted on American populations (pers. comm. Capt. TM Briers). Owing to this, the results are easily criticised and therefore the need to do a similar study on females in South Africa exists.

In a country such as South Africa, forensic investigators examine numerous cases involving skeletal remains, most cases of which are the result of unnatural deaths related to the high crime rate and accidental deaths by drowning etc. (Phillips 2001). The high number of unidentified victims, especially in rural areas, has often lead to the FFR procedure being practiced as a last resort at the Forensic Science Laboratory (FSL) in Pretoria, South Africa. According to Inspector T. Briers, 110 facial reconstructions have been performed in their laboratories over the past 7 years (pers. comm. Capt. TM Briers). No recent data on the success rate of the reconstructions are available.

Based on these problems experienced with FFR, the aims of this study are to:

1. Develop STT values for South African black females, to add to the existing literature or databases on STT values. Computerised tomography scanning (CT scans) will be used for this purpose.

2. Test the accuracy and recognisability of faces after being reconstructed with the newly developed standards.

3. Establish whether there is a significant difference between the outcomes after using North American-based values *versus* South African-developed values, and if it really influences the recognisability or success of the reconstructions.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Facial reconstruction, also referred to by many as facial approximation or reproduction (Snow 1970; Gatliff 1984; Rhine 1990; Stephan and Henneberg 2001; Turner *et al.* 2005; Wilkinson 2005; Domaracki and Stephan 2006; De Greef *et al.* 2006; Stephan and Cicolini 2008), is an attempt to reproduce the likely appearance of a face by building up the soft tissues onto a skull (El-Mehallawi and Soliman 2001) for the purpose of individual identification (Phillips and Smuts 1996; Kim *et al.* 2005).

When the usual efforts in establishing a positive identification are unsuccessful and few clues exist towards the identity of an individual, sculpting a reconstruction of the facial appearance may be helpful (Rogers 1987; Vanezis *et al.* 1989; Wilkinson 2005). It is applied as a last resort (Gatliff 1984; Nelson and Michael 1998; Phillips 2001; De Greef *et al.* 2006) to produce a lead towards the identification of unidentified skeletal remains (George 1987; Wilkinson 2005; Starbuck and Ward 2007).

The soft tissue and specific bony landmarks that it overlies have a direct influence on each other, which affects the outcome of the reconstruction. Forensic facial reconstruction (FFR) is concerned with examining and measuring the thickness and form of the soft tissues and attempting to understand how these tissues are spatially related to the underlying skull (Aulsebrook *et al.* 1995), with the objective that this relationship and facial morphology can be determined from skeletal detail with enough reliability to produce a recognisable representation of an individual (Wilkinson 2005). This has been investigated extensively, but many areas still lack data. Fortunately, many research opportunities have been identified for this field.

A brief overview of the history and development of FFR and areas linked to the field will be presented. Some case studies towards the success of the field will also be discussed.

2.2 TERMINOLOGY FOR FACIAL RECONSTRUCTION

Facial reconstruction refers to using the specific details and morphology of the skull to determine distinctive facial characteristics for an individual, and produce only one face from a skull (Wilkinson 2005). However, Rhine (1990) describes *reconstruction* as the reassembly of separate components of the same medium to form a complete structure, and therefore does not agree with the term *forensic facial reconstruction*. Rhine (1990) rather considers the term *reproduction* as an accurate or appropriate term to describe modelling of a face, from a medium that is different from the original, by applying clay onto a skull.

Facial approximation specifically refers to the practice of reproducing a facial type based on skull proportions, tissue thickness data and facial templates related to sex, age and race to produce many facial variations from the same skull (Wilkinson 2005). Stephan (2003) and others (Stephan and Henneberg 2001) prefer the term *approximation* as most appropriate, and criticised the use of *reconstruction* for many reasons. *Approximation* implies estimating what the face would have looked like in the living individual, but *reconstruction* implies creating an exact model of the face.

Nevertheless, *forensic facial reconstruction* remains a widely used and commonly accepted term, for example, as used by George (1987) and Aulsebrook *et al.* (1995), or in the title of the book "Forensic Facial Reconstruction" by Wilkinson (2004).

2.3 IDENTIFICATION OF SKELETONISED REMAINS

The identification of skeletonised remains has been one of the main focuses of interest for anthropologists for many years. Frequently, the aim of anthropologists is to put a face to the remains, especially if a skull is part of the remains found. This restoration of facial features on skulls of the dead has long intrigued anthropologists (Snow *et al.* 1970). This technique has been applicable to archaeological purposes where facial reconstruction has been undertaken to estimate the facial morphology of people of the past and to re-create the faces of historical figures recovered from ancient archaeological sites (Rhine 1990; Starbuck and Ward 2007). This is evident in the many historical reconstructions described by Prag and Neave (1997). It has also been useful for forensic purposes, such as to identify victims of crime, drowning or disappearance, in that it can help to create an idea of the appearance of the unknown individuals. In a forensic setting, the identification of human remains is a challenging task for which a variety of identification methods have been investigated. If no direct clues towards the identity of skeletal remains, such as an identity document, are found, the means of identification of remains is usually via fingerprinting, skull-photo superimposition, medical or dental record comparison, or DNA analysis (Vanezis *et al.* 2000; De Greef and Willems 2005; Wilkinson 2005; Burns 2007). However, it has happened in cases that none of these methods are possible, especially due to the fact that for all four methods mentioned existing information is needed. Therefore a clue towards the identity of the remains is first needed before records or samples can be collected for comparison to determine if there is a match.

FFR is a method attempting to provide such a lead. Different two- and three-dimensional (2D and 3D), manual and computer-aided techniques for FFR have been developed since the first attempts in the late 19th century (Quatrehomme *et al.* 1997; De Greef *et al.* 2006). After reconstruction of the likely appearance of the face on a skull, photographs of the final reconstruction are usually circulated via the media (newspapers or television shows such as *Crime Stop* broadcasted in South Africa), in the hope that somewhere in the public, a feature might spark the recognition of the face (Rhine 1990; Tyrrell *et al.* 1997; Reichs and Craig 1998) by relatives such that further evidence can be gathered (Rogers 1987; Claes *et al.* 2006). Further investigation, using comparative ante-mortem data, can then be made towards this lead for establishing the identity of the individual (Vanezis *et al.* 2000; De Greef *et al.* 2006).

2.4 THE HISTORY AND DEVELOPMENT OF FACIAL RECONSTRUCTION

2.4.1 The growing interest in facial reconstruction

Centuries ago many cultures had already attempted to preserve the bodies and restore the facial appearance of the deceased for all eternity. Prag and Neave (1997) described the plastered skulls found at excavation sites in Jericho, dating from C.7500 to 5500 BC, to be the first examples of facial reconstruction ever created. Another of the most well known examples or signs of attempts at facial reconstruction, is that of Egyptian mummification, especially in the form of death masks, which was found in Egyptian graves as early as 1370 B.C. (Wilkinson 2004). Many centuries later anatomical models started to appear, especially models that were created by artists who studied human dissection, many of whom were from North Italy, and were called *anatomical plastica artists* (Wilkinson 2004). During that time, wax models were very popular instead of using clay. Giulio Gaetano Zumbo (1656 – 1701) was such an artist pioneering in this field (Prag and Neave 1997).

Another Italian artist and sculptor, Ercole Lelli (1702 – 1766), produced a method of modelling the muscles with wax onto articulated human skulls, and produced beautiful and accurate results from his method (Prag and Neave 1997). These models were mainly used to assist in medical teaching.

This practice of wax modelling spread to the rest of Europe and England where, amongst anatomists, a great interest in facial reconstruction as an academic exercise appeared (Wilkinson 2004). During the late years of the 19^{th} century, German anatomists Welcker and His were the first to reproduce facial approximations from cranial remains (Rhine and Campbell 1980; Rhine 1990; Wilkinson 2004). Welker was an artist who attempted reconstructions of skulls of famous people such as Dante, Schiller and Kant (Nelson and Michael 1998), then compared them with portraits, to prove that it was indeed their skulls. His remodelled a plaster cast of the skull of the composer Johan Sebastian Bach and also compared it with self portraits of Bach, with favourable results (Nelson and Michael 1998; Prag and Neave 1997; Starbuck and Ward 2007).

Following His, other anatomists and artists, including Kollman and Büchly (1898), also attempted to sculpt the faces of famous people on their skulls (Rhine and Campbell 1980; Rhine 1990; Aulsebrook *et al.* 1995; Wilkinson 2004). The reconstruction of the face of a Stone Age woman from Auvernier, Switzerland, by Kollman and Büchly is considered to be the first scientific reconstruction (Wilkinson 2004; Starbuck and Ward 2007). Kollman, the anatomist, produced the technical plan for their study, which involved deriving soft tissue thickness (STT) values from hundreds of women in that area using a modification of Welker and His' techniques, and thereby made up the metrical or scientific part of their study (Prag and Neave 1997). Thereafter Büchly, the sculptor, employed his artistic skill to produce the 3D facial reconstructions of the skull of the Stone Age woman by using Kollman's data, which made up the artistic phase of their study (Prag and Neave 1997; Wilkinson 2004). This work was praised as one of the most remarkable achievements in the history of science-based reconstructions of faces from skulls (Wilkinson 2004).

This practice became better known, and by the early 20th century it had spread to be a popular practice exercised amongst anthropologists in various anthropological fields. However, in these early years, the 3D reproduction of faces seemed only to have been an interest for anthropologists to suggest the appearance of historical hominid forms, whose skeletons were recovered from archaeological sites (İşcan 1993; Rhine 1984). The independent reconstructions from the same skull of Neanderthals done by anthropologist Martin and Professor von Eggeling in 1913 (Prag and Neave 1997) are just some of the examples of the growing interest and study towards the application of this field.

Mikhail Gerasimov was another scientist who attempted palaeo-anthropological facial reconstructions in order to estimate the appearance of ancient individuals (İşcan 1993). Gerasimov (1907 – 1970) was a Russian archaeologist and anthropologist who developed the first standard technique of forensic facial reproduction. This method was based on anthropological, archaeological and forensic findings, and enhanced the fundamental importance of the development of musculature on the skull and neck (Prag and Neave 1997). He developed a manual for the 3D technique and used it on ancient skulls as well as in forensic cases (Quatrehomme and İşcan 2000). He studied the skulls and reconstructed the faces of more than 200 people, including Yaroslav the Wise, Ivan the Terrible, Friedrich Schiller, Rudaki and Tamerlane, and some succesful forensic cases (İşcan 1993; Prag and Neave 1997). Today this method is referred to as the "Russian method" and was first published in 1965 in Gerasimov's book *The Face Finder* which is still referenced and quoted by many researchers such as Gatliff (1984); Taylor (2001); Aulsebrook *et al.* (1995); Wilkinson (2004); Kim *et al.* (2005) and so forth.

During the late 1960s, the focus for the use of facial reconstruction seemed to shift as interest in forensic anthropology grew (Rhine 1984). In the 1970s anthropologists began to use facial reconstructions, hoping that it could be recognised as a scientific technique and provide a further lead towards the identity of individuals. Krogman and İşcan (1986), Snow *et al.* (1970) and Gatliff (1984) contributed greatly to the standardisation, data collection and popularity of the application of facial reconstruction to the forensic field. Krogman supported the work of Gerasimov through his tests on the facial reconstruction technique by concluding that the results were recognisable and the technique is useful in forensic identification (Prag and Neave 1997; Wilkinson 2004; Starbuck and Ward 2007). Snow *et al.* (1970) were of the first to attempt scientific testing of FFR (Aulsebrook *et al.* 1995). Gatliff (1984) and Snow *et al.* (1970) achieved outstanding results on their reconstructions, with a reported average identification rate of as high as 67% (Snow *et al.* 1970). They used a method of applying STT data on their reconstructions, adjusting to more modern data as it became available (Prag and Neave 1997).

Since then, through the pioneering works of Gerasimov, Krogman, Gatliff and many others, the process of FFR has been researched extensively, new data have been added, methods have been refined and it gradually became more common and generally more accepted in anthropology (Rhine 1990; Reichs and Craig 1998; Wilkinson 2004; Wilkinson 2005).

2.5 SOFT TISSUE THICKNESS AND BONY LANDMARKS

In facial reconstructions, STT values are commonly used to determine the amount or the depth of the tissues that fall on certain set landmarks on the skull (Wilkinson 2004; Domaracki and Stephan 2006). Besides the correct positioning of facial features such as the eyes, nose, mouth and ears, tissue depths are used to obtain an estimate of the facial outline (De Greef *et al.* 2006). This aids in the reconstruction of the face by giving a limit to work from when developing the initial face shape in the early stages of the reconstruction procedure. It has been the ultimate goal of many studies to determine how the function and growth of underlying bone surface influences the configuration of surface features of the face, and vice versa (Smith and Throckmorton 2006). The measurement of these STT values and establishment of landmarks has been researched extensively and has changed throughout the history of facial reproduction.

2.5.1 Methods used for soft tissue thickness estimations

Throughout the history of facial reconstruction, various methods have been employed to determine facial STT values (Phillips 2001). The earliest known research to quantify the relationship between the soft tissues and underlying relationship of the facial skeleton, was performed by Welcker in 1883 (Rhine 1990; Tyrrell *et al.* 1997; Tilotta *et al.* 2009). Welker studied the relationship of the facial tissues to the skull by using a method he described as blade-probing (Tyrrell *et al.* 1997). This involved inserting a thin blade into the skin of cadavers at selected anatomical landmarks (Quatrehomme and İşcan 2000). The blades were then marked at the tissue-surface-to-blade interface, and the depth of the blade's penetration was measured (Tyrrell *et al.* 1997).

His, a German anatomist, took measurements from a small number of cadavers by using a needle, which when pushed into the skin displaced a rubber disc (Nelson and Michael 1998). The rubber disc could slide on the needle, and when probing the cadaver with the needle, the rubber disc was slid to touch the skin surface, therefore indicating the depth of the underlying soft tissue (Rogers 1987; Sahni *et al.* 2008). His obtained a scientific database of average STT's in 1895 by measuring STT's on 24 male and 4 female cadavers (Snow *et al.* 1970; Gatliff 1984; Rhine 1990; Prag and Neave 1997) and used this average data for his facial reproductions.

In later research, a modified version of His' needle-probe technique was used by anatomists Kollman and Büchly in 1898, who used a soot-covered needle instead of a blade or needle with a rubber (Phillips and Smuts 1996; Domaracki and Stephan 2006). When the needle, blackened with soot from a candle flame (Rogers 1987), was pushed into the skin and removed, the contact with the skin left a clean area that was previously covered in soot (Sahni *et al.* 2008). The clear area now indicated the depth of the soft tissues and could be measured on an osteometric board (Nelson and Michael 1998; Domaracki and Stephan 2006). Kollman and Büchly added measurements of 21 male and 4 female white European cadavers in their study (Snow *et al.* 1970).

Since then many researchers have followed this technique to develop average tissue thickness databases, including Birkner (1905), Fisher (1905) and Von Eggeling (1909) who did cadaver studies on Chinese, Papuan and Hereron cadavers respectively (quoted from

Aulsebrook *et al.* 1995; Wilkinson 2004). Suzuki (1948), Rhine and Campbell (1980) and Rhine and Moore (1982) did cadaver studies on Japanese, black American, white American and South Western Indian groups respectively. Wilkinson (2004) published many tables on STT data from various researchers, including the results of these mentioned studies, the authors who are still amongst the most famously quoted.

A very recent study based on the needle probing guideline described by Kollman and Büchly was conducted by Domaracki and Stephan (2006) on 33 caucasoid cadavers from Australia; 19 males and 14 females. They have motivated that despite its weaknesses, the needle puncture method had a number of advantages, such as the subjects do not move, and the equipment is inexpensive and simple to use (Domaracki and Stephan 2006; Codinha 2009). Codinha (2009) motivated the cadaver study on 151 Portuguese individuals, 103 males and 48 females, with the same reasons. Tedeschi-Oliveira *et al.* (2009) have motivated the use of cadavers in their study in that measurements could be made at any point with simple instruments and that the examiner need not be exposed to radiation. They have also used the needle puncture method of taking measurements with a dental needle with a silicone marker stop on 40 Brazilian cadavers; 26 males and 14 females. However, the use of cadavers for the development of STT values has been much criticised and questioned for its accuracy for many reasons (De Greef *et al.* 2006): cadavers can suffer from post mortem soft tissue distortion due to putrefaction, dehydration and embalming (Snow *et al.* 1970; Phillips and Smuts 1996; Tyrrell *et al.* 1997; Wilkinson 2004; De Greef *et al.* 2006; Galdames *et al.* 2008) or any other changes that occur in the first few hours after death, like loss of muscle tone and shrinkage of soft tissues (Helmer *et al.* 1993; Sahni *et al.* 2008). The supine position is also felt to create false measurements due to gravity causing tissues to pull backward and affect the natural drape of facial tissues (Aulsebrook 1996; Wilkinson 2004; De Greef *et al.* 2006). Furthermore, the use of cadavers has also proved to be unreliable because of the difficulty determining the position of some landmarks through palpation of the cadavers while flesh is still covering the skull (Quatrehomme and İşcan 2000; Starbuck and Ward 2007; Sahni *et al.* 2008), and the difficulty in ensuring that the probe is orientated perpendicular to the underlying bone (Kim *et al.* 2005). When probing a cadaver, the insertion of the probe may cause some depression of the skin (Kim *et al.* 2005), resulting in an underestimated value of the underlying soft tissue. Another negative aspect is the difficulty in finding a large sample size to represent a specific population group (Kim *et al.* 2005), especially if the study requires fresh, and not embalmed, cadavers. It is difficult to access fresh cadavers before many hours or days have past (Rhine and Campbell 1980). Since cadaver studies have been shown to be less ideal, scientists have shifted the focus to other methods of soft tissue measurement.

In the later years of the 20th century, following the development of modern technology, more recent and advanced methods were employed in taking soft tissue depth measurements. Advances in technology made it possible to significantly improve the quality and quantity of tissue depth data being measured (Tyrrell *et al.* 1997). These advances include capturing digital data from living 3D images using ultrasound and cephalometric radiographs (Aulsebrook 1996), under which fall magnetic resonance imaging (MRI) and computerised tomography (CT) scans (Phillips and Smuts 1996; Tyrrell *et al.* 1997; El-Mehallawi and Soliman 2001; Turner *et al.* 2005; Starbuck and Ward 2007). These methods have been shown to be accurate in taking STT measurements (Aulsebrook *et al.* 1996).

Ultrasound has been used since the 1960s, but requires specialised apparatus not always freely available. It has the advantages of being safe, that is no risk of radiation exposure to the subjects (Nelson and Michael 1998), non-invasive and accurate (Manhein *et al.* 2000). Subjects can be measured in an upright sitting position (De Greef *et al.* 2006) and large sample sizes can be measured. Since measurements can be taken from living people, it is likely to be a more accurate representation of a living person's face in contrast to measurements taken on cadavers (Stephan and Henneberg 2001). Ultrasound has been found useful and has been the method of choice for many modern researchers on soft tissue measurement (Aulsebrook *et al.* 1995; Phillips and Smuts 1996; Manhein *et al.* 2000). Some criticism towards ultrasound is that the procedure requires a lot of training since it is difficult to interpret the images and control the equipment (Sahni *et al.* 2008). Subjective errors may occur in the angulation of the ultrasonic probe with bone (Sahni *et al.* 2008), since the angle to the bone at which the measurement is taken alters the value of the measurement (Nelson and Michael 1998), and holding the probe perpendicular to the skin surface does not necessarily mean that the depth will be measured perpendicular to the bone. Also, when the probe is pressed against the skin, it may cause some depression (Aulsebrook *et al.* 1996) of the skin surface and result in underestimation of the tissue thickness.

CT scanning is a technique that uses a computer to reconstruct a 3D image of the internals of an object from a large series of 2D radiographic images (i.e. axial and coronal slices) (Rocha *et al.* 2003), and produces a clear image of the internal macro-anatomy of the human body. It has been applied in several different clinical settings (Rocha *et al.* 2003) such as studying internal pathologies of organs and bones, but also has been useful in other fields of study. It has been particularly useful in anthropometric studies since it provide good definitions of both the skull and face images (Tilotta *et al.* 2009). High image contrast is seen between the bone (appearing white due to higher radiodensity) and subcutaneous soft tissues or musculature (appearing grey to dark), as well as the soft tissue versus air (Turner *et al.* 2006; Vandermeulen *et al.* 2006). One can clearly detect the margins of the bone and skin (Shimofusa *et al.* 2009), therefore making it possible to take an accurate measurement from a specific landmark on the bone to the surface of the skin (Tyrrell *et al.* 1997). This distance is called the tissue depth. The CT scan procedure is not without criticism when applied for measuring facial tissue thickness. One drawback is that

CT images require patients to be in a horizontal supine position, with the result that the facial shapes may differ from the typical face shape when in a standard upright position, due to gravitational forces (Claes *et al.* 2006). Recruiting subjects might also pose some difficulty, since a CT scanner can not be carried around like an ultrasound can; therefore, if live subjects are required, the volunteers have to come to the observer. This may be problematic if the population group to be measured is in the rural areas and transport or access to a CT machine is difficult. Due to radiation exposure, although small, CT scanning remains limited to patient samples to avoid unnecessary radiation to volunteers (Smith and Throckmorton 2006).

A scientist must consider all the aspects of the different methods to make the choice of the method used for tissue depth measurement when attempting to develop a database of STT, but the choice will also be dependent on whether equipment, funding and time is available. Table 2.1 shows a summary of different methods used by researchers throughout the history of tissue thickness measurements. With the advances in technology, the increasing need and demand for facial identification of individuals, growing interest in FFR and refining of methods, many other researchers have contributed to the data collection on adults and children, males and females, from Caucasian, Mongoloid, Negroid, Native American and various other population groups (Rhine and Campbell 1980; Helmer *et al.* 1993; Lebedinskaya *et al.* 1993; Aulsebrook *et al.* 1996; Phillips and Smuts 1996; Tyrrell *et al.* 1997; Manhein *et al.* 2000, Farkas *et al.* 2005; Turner *et al.* 2005; De Greef *et al.* 2006; Starbuck and Ward 2007; Sahni *et al.* 2008; Codinha 2009; Shimofusa *et al.* 2009; Tedeschi-Oliveira *et al.* 2009; Tilotta *et al.* 2009).

2.5.2 Variations in defined landmarks

The standardisation and adequate description of the landmarks where STT is recorded is just as important as the method for measurement. A major source of error originates from the inaccurate location or ambiguous nature of some definitions of landmarks (Nelson and Michael 1998). DeCarlo *et al.* (1998) define the term *landmark* as visible or palpable features, whether skin or bone, on a subject. Many landmarks are not described as a specific point, but a general region. Variation in the exact point of measurement may exist and it can influence the results greatly. This also influences the application of the markers where, if the position is not a clear spot but the artist has to judge an area, the outcome of the reconstruction can be altered greatly. Furthermore, even when referred to the same landmark, there often is no agreed upon definition of the individual landmarks (Brown *et al.* 2004; Stephan and Simpson 2008). Brown *et al.* (2004) published summarised collective tables of tissue-depth landmarks that were used for many years in studies to create data tables for these landmarks. These tables include the definitions and the reference to who has first defined or described that landmark. Table 2.1 includes a similar summary of the number of landmarks and methodologies that different researchers used in their studies throughout the progression of developing STT data.

The anthropological landmarks defined for the measurement of STT have not changed much since the first establishment by His in 1895. His measured nine midline and six lateral anatomical landmarks, 21 in total (Prag and Neave 1997). Kollman and Büchly (1898) included three more points to His' in their study in 1898, and these standards are today still well known to practitioners of FFR (Aulsebrook *et al.* 1995).

Aulsebrook *et al.* (1996) put together an extensive list of 54 landmarks with their detailed descriptions or definitions, consisting of 16 landmarks which can be applied to lateral cephalometric radiographs, 20 to oblique cephalometric radiographs, and 18 for ultrasonic measuring. These are more landmarks than previous studies of this kind, and focussed specifically on the importance of the oblique profile in identification (Aulsebrook *et al.* 1996).

Stephan and Simpson (2008) compiled a table from pooled data describing the definitions for landmarks from skeletal points (hard tissue) and their relevant soft tissue points, that is, where the landmark is positioned on the face instead of on the skull. Having both is useful in that it ensures repeatability by standardising the direction from the bone to skin surface that a measurement is taken in any of the methods used for STT measurement.

The landmarks chosen depend on the areas of interest or areas where variation could occur and are especially influenced by age, ancestry, sex and body build. These areas should be clearly defined and be practical to measure. The 21 anthropological landmarks defined by Rhine and Campbell (1980), illustrated in Figure 2.1 and Table 2.2, are most often used by researchers, at least as a basis from which landmarks are chosen in a new study. The forensic artists in South Africa also currently use the Rhine and Campbell landmarks when creating FFR's (pers. comm. Capt. TM Briers). Furthermore, the landmarks established by Suzuki (1948) (Figure 2.2) are also frequently quoted and compared by many modern researchers. The names for Suzuki's landmarks are slightly different, but refer to the same points as that of Rhine and Campbell (1980) (Compare Figures 2.1 and 2.2 and Table 2.2).

The sparsity of landmarks has been said to be problematic, particularly in the cheek region, since it may cause reconstructions to appear to have hollow cheeks (Nelson and Michael 1998). This supports the use of a higher amount and wider spread of landmarks across the face. It can be assumed that the more measurements are recorded or applied, the better the chance will be of rendering a more prefect likeness of the unknown face (Aulsebrook *et al.* 1995). The number of landmarks for the measurements usually varies from 15 to 34 (Wilkinson 2004), as researchers may leave some out or include some. Wilkinson (2004) illustrates the different terms for the same 39 points extensively.

Table 2.1 The history and methodology of tissue thickness measurements (Adapted and updated from Brown *et al.* 2004 and Rhine and Campbell 1980)

Author (year of study)	Method of collection	Number of landmarks	Sample size (group)
Welcker (1883)	Knife blade probing	9 (mid)	13 (White; ♂)
His (1895)	Needle with rubber disc	15 (9 mid, 6 lat)	28 (White; 24♂, 4♀)
Kollman and Büchly (1898)	Soot-covered needle	18 (10 mid, 8 lat)	25 (White; 21♂, 4♀)
Suzuki (1948)	Needle probing	24 (10 mid, 14 lat)	55 (Mongoloid; 48♂, 7♀)
Rhine and Campbell (1980)	Needle with rubber disc	21 (10 mid, 11 bilat)	59 (Black; 44♂, 15♀)
Rhine and Moore (1982)	Needle with rubber disc	21 (10 mid, 11 bilat)	73 (White; 48♂, 25♀)
Helmer (1984)	Ultrasound	34	11 (White)
George (1987)	X-ray (lateral cephalographs)	13 (mid)	54 (White; 17♂, 37♀)
Lebedinskaya *et al.* (1993)	Ultrasound	20	1695 (Mixed group including Koreans, Buryats, Kazakhs, Bashkirs, Uzbeks, Armenians, Abkhazians, Russians & Lithuanians; 845♂, 850♀)
Aulsebrook *et al.* (1996)	Radiographs and ultrasound	54	55 (Black; ♂)
Phillips and Smuts (1996)	CT scans	21	32 (Mixed race; 16♂, 16♀)
Manhein *et al.* (2000)	Ultrasound	19	197 (Black; 22♂, 44♀) (White; 48♂, 82♀)
De Greef *et al.* (2006)	Ultrasound	52 (10 mid, 21 bilat)	967 (White; 457♂, 510♀)
Domaracki and Stephan (2006)	Needle probing	13 (10 mid, 3 bilat)	33 (White; 19♂, 14♀)
Sahni *et al.* (2008)	MRI	29 (13 mid, 16 bilat)	300 (Indian; 173♂, 127♀)
Codinha (2009)	Needle probing	20 (8 mid, 12 bilat)	151 (Portuguese; 103♂, 48♀)
Shimofusa *et al.* (2009)	CT scans	10	50 (Japanese; 33♂, 17♀)
Tedeschi-Oliveira *et al.* (2009)	Needle probing	21 (10mid, 11 bilat)	40 (Brazilian; 26♂, 14♀)
Tilotta *et al.* (2009)	CT scans	39 (13mid, 13 bilat)	85 (White)

mid – midline landmark
lat – lateral landmark
bilat – bilateral landmark (measured on both sides of the face)
♂ – male
♀ – female

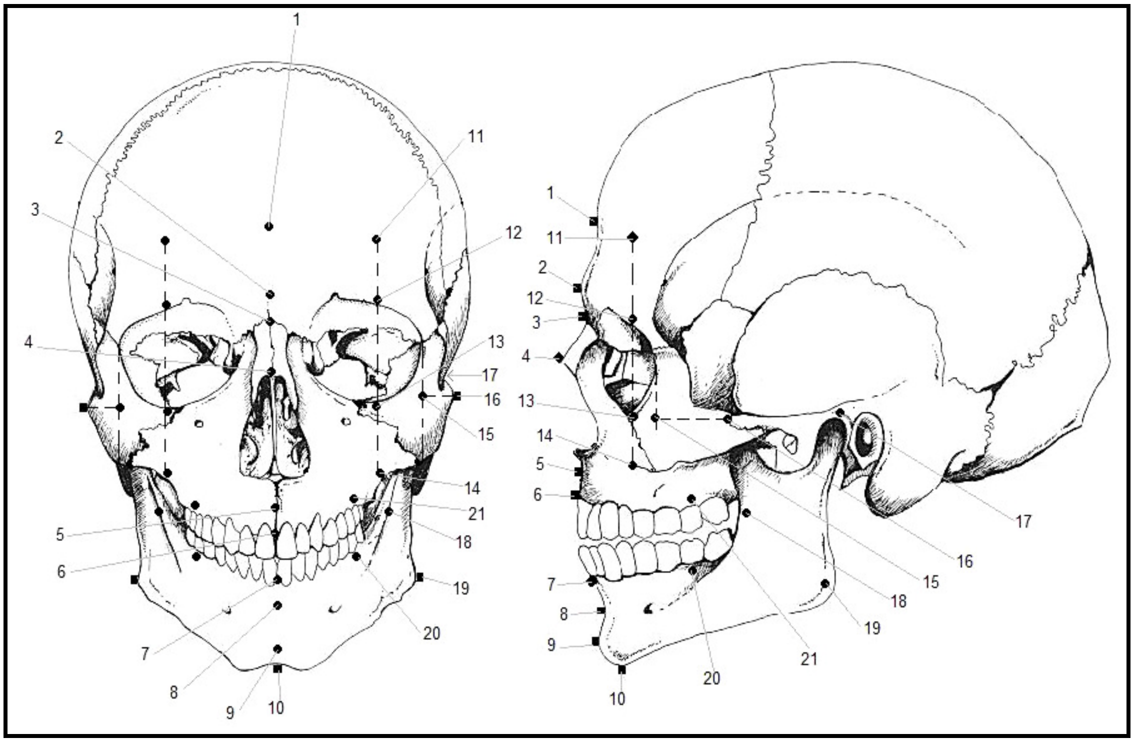

Figure 2.1 Landmarks for facial tissue measurements according to the method of Rhine and Campbell (1980). The labels are explained in Table 2.3

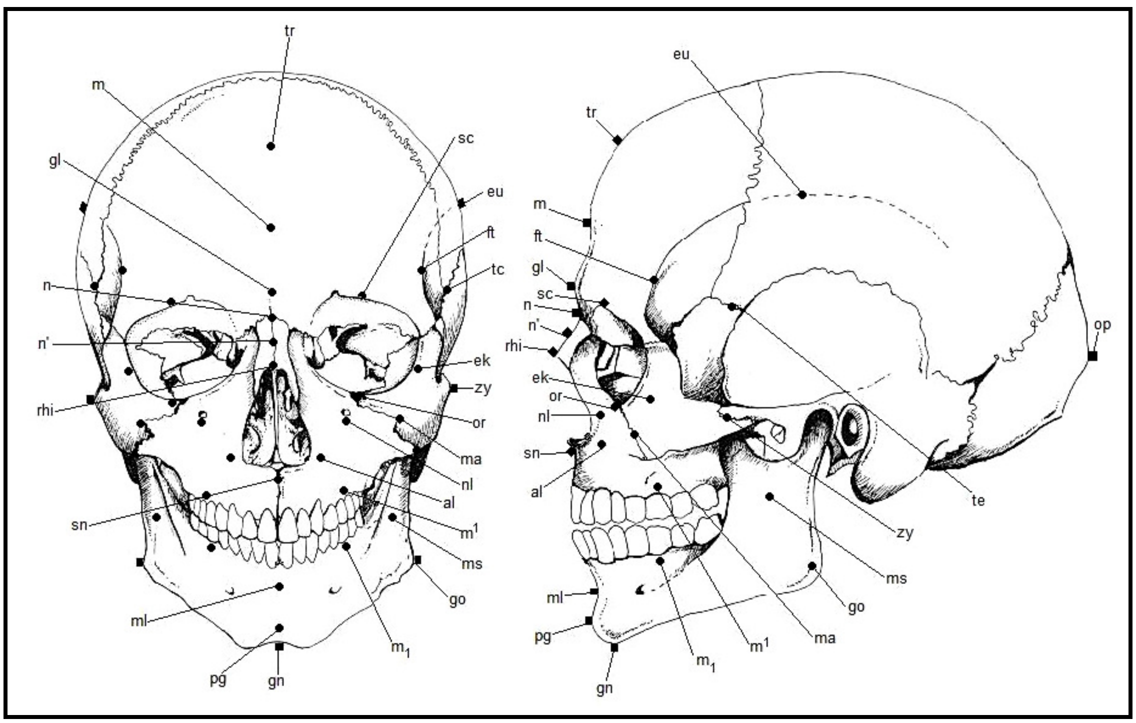

Figure 2.2 Landmarks for facial tissue measurements according to the method of Suzuki (1948). The labels are explained in Table 2.3

Table 2.2 Landmarks for facial measurements (adapted from Rhine and Campbell 1980) and definitions according to Rhine and Campbell (adapted from Taylor 2001). Definitions for additional landmarks by Suzuki (1948) adapted from Wilkinson (2004) and Wilkinson (2007)

Landmarks according to Suzuki	Landmarks according to Rhine and Campbell	Definitions, as described by Rhine and Campbell
m – metopion	1 – supraglabella	Above the glabella
gl – glabella	2 – glabella	Most prominent point between the supraorbital ridges in the midsagittal plane
n – nasion	3 – nasion	Midpoint on the suture between the frontal and two nasal bones
rhi – rhinion	4 – end of nasals	Anterior tip of the furthest point out on the nasal bones
sn – subnasale	5 – mid-philtrum	Point in the midline of the maxilla, as high as possible before the curvature of the anterior nasal spine begins
-	6 – upper lip margin	Centered between the maxillary (upper) central incisors at the level of the cementum-enamel junction
-	7 – lower lip margin	Centered between the mandibular (lower) central incisors at the level of the cementum-enamel junction
ml – mid labio-mentale	8 – chin-lip fold	Deepest midline point of indentation on the mandible between the teeth and the chin protrusion
pg – pogonion	9 – mental eminence	Most anterior projecting point in the midline on the chin
gn – gnathion	10 – beneath chin	Lowest point on the mandible
-	11 – frontal eminence	Place on the projections at both sides of the forehead
sc – supraciliary	12 – supraorbital	Slightly above the orbit, centered on the upper most margin or border, or the upper middle ridge of the orbit
or – orbitale	13 – suborbital	Slightly below the orbit, centered on the lowermost margin or border
	14 – inferior malar	Lower portion of the maxilla, still on the “cheekbone”
-	15 – lateral orbits	Drop a line from he outer margin of the orbit and place the marker about 10 mm below the orbit
zy – zygion	16 – zygomatic arch	Halfway along the zygomatic arch, generally the most projecting point on the arch when viewed from above
-	17 – supraglenoid	Above and slightly forward of the external auditory meatus (ear hole) at the deepest point
-	18 – occlusal line	On the mandible, in alignment with the line where the teeth occlude or “bite”
go – gonion	19 – gonion	Most lateral point on the mandibular angle
m_1 – sub-M_1	20 – sub-M_2	Below the first (M_1) or second (M_2) mandibular molar
m^1 – supra-M^1	21 – supra-M^2	Above the first (M^1) or second (M^2) maxillary molar

Additional landmarks by Suzuki (1948)	Definitions
tr – trichion	Midpoint of the hairline
ft – frontotemporale	Lateral point from the elevation of the linea temporalis, of the terminal points of the tail of the eyebrow
n’ – lowest point of ridge of the nose	The midpoint of the nasal bones, on the internasal suture midway between nasion and rhinion
ek – exocanthion	A point on the lateral orbital margin on a line with the eye fissure
nl – nose-lip groove	A point on the lateral nasal bone that is related to the naso-labial fold
al – alare	The most lateral point on each alar contour, also known as the supra-canine
ma – malare	Point of the zygomatic muscle attachments on the cheek bone or zygomaxillare
ms – (mid)masseter	The midpoint of the zygion (zy) and gonion (go)
eu – euryon	Cranial point where the cranial breadth is greatest
te – pterion	A point on the pterion, that is, the suture where the frontal, parietal, temporal and bones meet, vertically up from the zygion
op - opisthocranion	Most posterior point at the back of the head (external occipital protruberance)

2.5.3 Variations in soft tissue thickness values

The STT values are thought to be influenced by age, ancestry, sex and body build, and after many research studies significant differences were found in the thicknesses of the soft tissues of these various groups (Suzuki 1948; Gatliff and Snow 1979; Rhine and Campbell 1980; Lebedinskaya *et al.* 1993; Phillips and Smuts 1996; Simpson and Henneberg 2002; De Greef *et al.* 2006; Sahni *et al.* 2008; Codinha 2009; Tedeschi-Oliveira *et al.* 2009). Different tissue thicknesses can result in variations that have the potential to influence the eventual outcome of a facial reconstruction and the recognition thereof (Tyrrell *et al.* 1997). Claes *et al.* (2006) illustrated the changes that properties such as body mass index (BMI), age and sex bring to the average face. However, it has been stated, though, that the factors constituting the likeness of a face are more dependent on proportions than finite measurements (Aulsebrook *et al.* 1996). Still, it is useful to have a standard to work according to, especially when no clues towards the body constitution of the unknown individual have been found.

These variables have been the focus of many studies in FFR, for example, that of Manhein *et al.* (2000) and Sahni *et al.* (2008), who found significant differences in tissue thickness between sexes, ancestral groups and a significant relationship between tissue thickness and age. Sahni *et al.* (2008) reported a correlation of STT with advancing age, which may be attributed to wrinkling and other effects of aging such as decrease in tensile strength or decrease thickness of collagen fibres in the dermis. Developing STT values for different BMI categories have been popular in many studies, since it was observed that STT vary considerably and not in a linear manner when the BMI is introduced as a variable (Codinha 2009). Environmental conditions, socioeconomic status and nutritional habits of populations are also factors that have been identified to influence the variations in facial morphology (Quatrehomme *et al.* 1997; Farkas *et al.* 2005; Tedeschi-Oliveira *et al.* 2009). These variables are again influenced by regional population diversity (Sahni *et al.* 2008) or genetic and geographic factors, that play a major role in the development and changes of the muscular and fatty tissue covering the skull of an individual (Manhein *et al.* 2000).

Farkas *et al.* (2005) conducted an extensive research study, wherein one of the aims was to identify the craniofacial region(s) that contribute most to significant differences between ancestral groups. They attempted to establish the main facial characteristics of different "races" and thereby illustrate the different morphological facial differences between the various ancestral groups. Significant differences were found in some features.

Studies have shown that the measurements between the right and left sides of the face are not significantly different (Sutton 1969; Domaracki and Stephan 2006; Tedeschi-Oliveira *et al.* 2009). However, Sahni *et al.* (2008) have found slight asymmetry in most of the bilateral landmarks, with minute differences in the measurement values. De Greef *et al.* (2006) reported that the differences between the right and left sides of the face are so small in absolute (< 1mm) and relative (< 6%) values, that it is most probably not significant from a craniofacial approximation point of view. Therefore, scientists rather focus on differences between different population groups, or age and body sizes within population groups.

Since differences in STT exist between particular groups, the need has been stressed for additional data collection in an attempt to increase the accuracy of the reconstructions (Domaracki and Stephan 2006). These differences seem unpredictable, and since the area or features where the differences occur vary in all the studies conducted, the need to establish a STT database specific for each population group (and variances thereof) is paramount. Researchers are attempting to establish databases for every age group, population group, sex and class of body build (based on BMI), but it will still take many studies to complete an accurate database for all the above-mentioned groups around the globe.

The most frequently quoted and compared databases of STT's are that of Rhine and Campbell (1980) for "Negroid", Rhine and Moore (1982) for "Caucasoid" and Suzuki (1948) for "Mongoloid" (or Japanese) (Figures 2.1 and 2.2; Tables 2.2 and 2.3). Researchers who have practically applied these to specific cases or used these in their studies for comparison to recent results include Gatliff (1984); Aulsebrook *et al.* (1996); Phillips and Smuts (1996); Prag and Neave (1997); Manhein *et al.* (2000); Taylor (2001); Wilkinson (2004); De Greef *et al.* (2006) and Sahni *et al.* (2008).

Table 2.3 Comparison of soft tissue thicknesses (millimetres) of American Negroids (African derived, by Rhine and Campbell, 1980), American Caucasoids (European derived, by Rhine and Moore, 1982) and Mongoloids (Japanese derived, by Suzuki, 1948)

	Rhine and Campbell		Rhine and Moore		Suzuki	
	Black male	Black female	White male	White female	Japanese male	Japanese female
Supraglabella	**4.75**	**4.50**	**4.25**	**3.50**	**3.00**	**2.00**
Glabella	**6.25**	**6.25**	**5.25**	**4.75**	**3.80**	**3.20**
Nasion	**6.00**	**5.75**	**6.50**	**5.50**	**4.10**	**3.40**
End of nasal bone	**3.75**	**3.75**	**3.00**	**2.75**	**2.20**	**1.60**
Mid-philtrum	**12.25**	**11.25**	**10.00**	**8.50**		
Upper lip margin	**14.00**	**13.00**	**9.75**	**9.00**		
Lower lip margin	**15.00**	**15.50**	**11.00**	**10.00**		
Chin-lip fold	**12.00**	**12.00**	**10.75**	**9.50**	**10.50**	**8.50**
Mental eminence	**12.25**	**12.25**	**11.25**	**10.00**	**6.20**	**5.30**
Beneath chin	**8.00**	**7.50**	**7.25**	**5.75**	**4.80**	**2.80**
Frontal eminence	**8.75**	**8.00**	**4.25**	**3.50**		
Supra orbital	**4.75**	**4.50**	**8.25**	**7.00**	**4.50**	**3.60**
Infra orbital	**7.75**	**8.25**	**5.75**	**6.00**	**3.70**	**3.00**
Inferior malar	**17.00**	**17.75**	**13.25**	**12.75**		
Lateral orbit	**13.25**	**12.75**	**10.00**	**10.75**	**5.40**	**4.70**
Zygomatic arch	**8.50**	**9.00**	**7.25**	**7.50**	**4.40**	**2.90**
Supra glenoid	**11.75**	**12.25**	**8.50**	**8.00**		
Occlusal line	**19.00**	**19.25**	**18.25**	**17.00**		
Gonion	**14.75**	**14.25**	**11.50**	**12.00**	**6.80**	**4.00**
Sub M_2 (mandible)	**16.50**	**17.25**	**16.00**	**15.50**	**10.20**	**9.70**
Supra M^2 (maxilla)	**22.00**	**21.25**	**19.50**	**19.25**	**14.50**	**12.30**

On the reconstruction itself, the thickness of the soft tissue can also be influenced by the cutting of the markers for tissue depth. Many times these markers are vinyl ester strips, with a diameter of about 6 mm. This is a difficult thickness on areas where finer pinpointing is needed, and the use of more solid and finer material could be handy (Taylor 2001). To cut the length of the tissue markers to 0.1 of a millimetre is almost practically impossible, unless a microscope and extremely thin blade is used. Therefore many researchers round off the average value for their tissue thicknesses to the nearest 0.2 mm, some even to the nearest 0.5 mm (Stephan and Henneberg 2001; Codinha 2009), which is a more practical length for cutting. The data published by Rhine and Campbell (1980) (Table 2.3) were read off a metric scale to the nearest 0.25 mm. Aulsebrook *et al.* (1996) stated that although the fine degree of measurement could be of use in other studies, when it comes to the practical stages of reconstruction, the figures may be rounded to the nearest 0.5 mm because of the relative crudeness of manual control in modelling.

2.6 PRINCIPLES, BACKGROUND, DIFFERENT METHODS AND PROCEDURES OF FORENSIC FACIAL RECONSTRUCTION

2.6.1 The skull and preparation for reconstruction

The skull is the basis for facial reconstruction, therefore knowledge of the skull in general, that is, the osteological landmarks, as well as the features that individualise the skull, that is, a specific abnormality or feature on any of the areas or landmarks, is necessary for the reconstructor to continue with his or her work. After assessment of the skull by a forensic anthropologist, a forensic report is compiled, containing details such as the age, sex and ancestry (Gatliff 1984; George 1987; Vanezis *et al.* 2000; Gatliff and Taylor 2001; De Greef and Willems 2005). Examination of the skull should also focus on the identification of any bony pathology (injury or disease) or unusual landmarks, ruggedness of muscle attachments, profile of the mandible, dentition, wear of the occlusal surfaces, asymmetry, individual anomalies (Gatliff 1984; Rathbun 1984; Taylor and Angel 1998; Quatrehomme and İşcan 2000; Vanezis *et al.* 2000; Wilkinson 2004) and any other features that may have an effect of the appearance of the individual's face. Rhine and Campbell (1980) described the identification of these individualising anomalies as extraction of the peculiarities and emphasising the idiosyncrasies inherent in the skull. Should it be necessary to send the skull away for FFR, the forensic report, together with any other associated evidence such as clothes, jewellery, glasses or hair which could help with individualisation, should be handed to the forensic facial reconstructor, who would then attempt to reconstruct the face using all the known data (Gatliff and Taylor 2001). These extra physical evidence pieces found with remains have often proven to be valuable, since they directly reflect the appearance of the unknown individual (Taylor and Angel 1998).

Frequently, the skulls handed in for reconstructions are damaged and missing some parts, and in these cases it is important to identify the fragments and to assess whether there is sufficient material to work on or to rebuild the skull. Fragmented or missing elements can be restored or remodelled with wax onto the skull (Rogers 1987; Prag and Neave 1997). Studies have shown that missing areas can be accurately established by assessing the surrounding bones or even, when a side of the skull is missing, assessing the other side of the skull (Wilkinson 2004). However, mirror image reconstruction of the skull will also affect the reconstruction of the face (Wilkinson 2004). One must realise that skulls and faces can be asymmetrical, but the asymmetry has to be extreme before it begins to affect the outward appearance of the face significantly (Prag and Neave 1997). Fortunately, slight errors in restoring the missing portions of a skull can usually be accommodated.

Reconstructions can be carried out on the skull itself, or on an exact replica of the skull, which is done by casting it with plaster of Paris or making a sculptural reproduction

(Rogers 1987). Often the original skull must remain preserved for further examination, legal purposes or, for example, if identification of the individual is successful, the family may want the remains for emotional and burial purposes. If the skull is covered with clay, and even if removal is possible, the process of reconstruction may have damaged the skull. Furthermore, some specimens may be too fragile to support the weight of the clay used for the reconstruction and may cause irreversible damage (Prag and Neave 1997). Many artists therefore choose to rather create a cast of the skull to model the face. An advantage to keeping the original skull preserved is that the artist will have a reference to look back on for checking its form and measurements (Rogers 1987; Vanezis *et al.* 1989). Once the bony landmarks are covered with clay, the 3D appearance of the bone is hidden and it is difficult to predict features from 2D photographs of the skull, even if taken from many angles. Furthermore there is no risk of damage to the original and a cast provides a must sturdier framework upon which to work (Vanezis *et al.* 1989). Also, when a mould is created and it is unsatisfactory, the casting can be repeated, but a damaged specimen is irretrievable and the original can never be replaced (Prag and Neave 1997).

The Frankfurt Horizontal Plane (Figure 2.3) has been known to be a useful position to mount the skull for facial reconstructions. It is defined as a standard anthropological position that closely approximates the natural position of the head in life (Taylor 2001). This position is achieved by orientating the skull so that the lower orbital margins are aligned horizontally with the most superior and lateral point of the roof of the external auditory meatus, with this imaginary horizontal line then lying parallel to the ground (Krogman and İşcan 1986; Prag and Neave 1997; DeCarlo *et al.* 1998; Taylor 2001; Starbuck and Ward 2007).

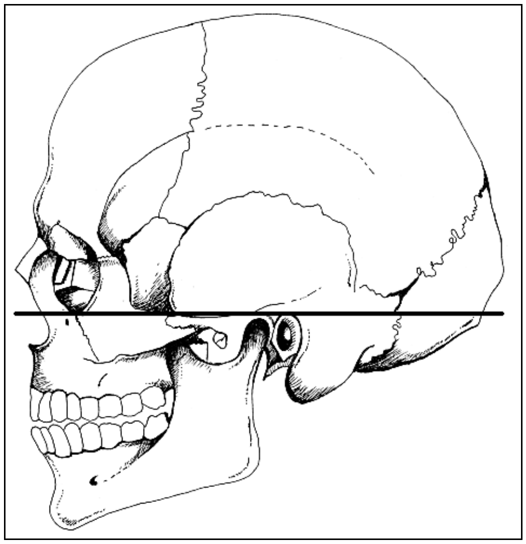

Figure 2.3 The Frankfurt Horizontal Plane

2.6.2 The methods and techniques of facial reconstruction

There are numerous techniques to sculpt a face onto the skull (Phillips 2001). All the methods of facial reconstruction, whether created with clay or computer generated, rely on a hypothesised relationship between the facial features, subcutaneous soft tissues and underlying bony structure of the skull (Tyrrell *et al.* 1997; Wilkinson 2004; Turner *et al.* 2005; Stephan 2006). For this reason, the reconstructor needs to have some scientific knowledge and practical understanding of the osteology and anatomy on the skull and face (Aulsebrook 2000), and be willing to model the reconstruction with a consideration for scientific accuracy rather than artistic style (Rogers 1987). Still, the sculptor also needs the personal experience, artistic skill and intuition (Snow *et al.* 1970) to work with the medium used to produce the shapes, contours and facial appearance of a realistic looking face (Aulsebrook 2000).

Any of the methods of FFR is composed of two main stages, which together reveal FFR as a combination of science and art (Phillips and Smuts 1996; Phillips 2001; Taylor 2001; Kim *et al.* 2005; De Greef *et al.* 2006). The first phase is the technical or mechanical phase of information collection, skull preparation (Wilkinson 2004) and applying the soft tissue data of muscles to the skull to establish a general facial shape (Gatliff and Taylor 2001). This involves placing markers that represent the corresponding STT measurements at specified landmarks (Tilotta *et al.* 2009), using pooled data on the surface of the skull, and filling the intervening spaces with clay (Rhine and Campbell 1980). The second phase is the development of individual features and areas of transitions, therefore known as the artistic phase (Gatliff and Taylor 2001; Wilkinson 2004). The artistic phase is considered by many to be more subjective (Helmer *et al.* 1993). This phase involves the shaping of the nose, mouth, cheeks, ears, overall face shape and adding the finishing touches. A large amount of literature (e.g. Taylor 2001; Wilkinson 2004) exists that includes general guidelines on determining the shapes and sizes and projections of the various facial features, but the technique used will again depend on the preference of the artist. Much uncertainty lies in the guidelines for forming the various features, therefore the accuracy is still questioned and this area is easily criticised. This is very unfortunate, since people tend to remember faces and recognise each other by the appearance of facial characteristics (Roelofse *et al.* 2008) and not always by the total face as a whole, and even less the face's shape alone. Thus, it is the reconstruction of these features that can make the difference between a positive and a false identification.

Many different facial reconstruction techniques have been developed, among them the 2D reconstruction method and different variations of the 3D (plastic) method (Quatrehomme *et al.* 1997; Taylor 2001). It is up to the reconstructor to decide on the appropriate technique to use. There are many factors to consider when making this decision. These factors include which technique the reconstructor has more knowledge, skill, experience and confidence in, the time the reconstructor has to produce the reconstruction, and whether the right equipment is available for the desired technique. The reproduction of a face is a time consuming task that requires some artistic skill to accomplish properly (Rhine and Campbell 1980; De Greef and Willems 2005).

2D facial reconstructions are hand-drawn facial images. These drawings are based on ante mortem photographs of the skull and any other detail available on the unknown individual. A commonly used method of 2D facial reconstruction was created by Karen T. Taylor during the 1980s. Taylor's method involves applying tissue depth markers on an unidentified skull at various anthropological landmarks, then photographing the skull (Taylor 2001). Frontal and lateral photographic prints are then used as a foundation for facial drawings done on tracing paper overlaying the photographs (Figure 2.4).

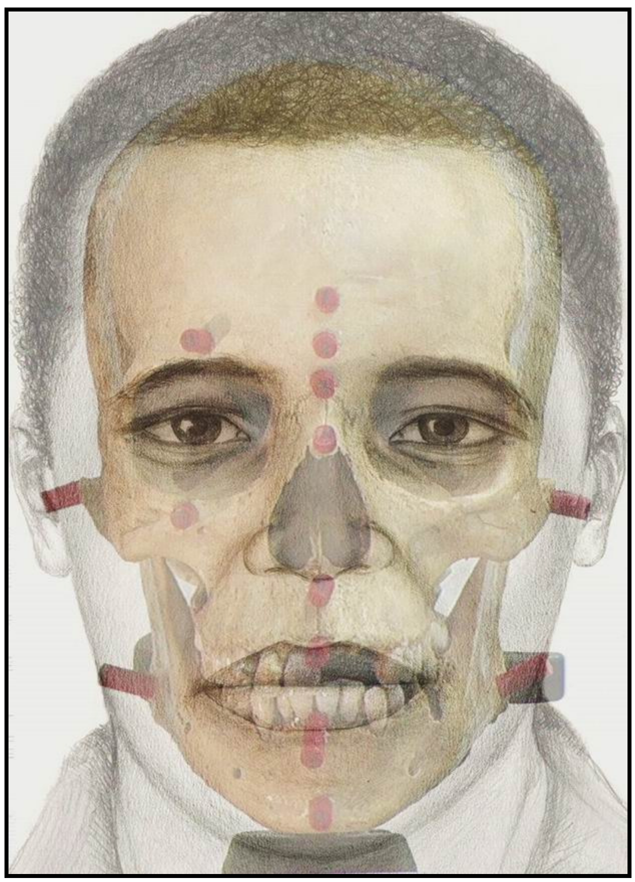

Figure 2.4 An example of a 2D reconstruction, superimposed on the skull with pegs glued on as tissue thickness indicators (Courtesy of the SAPS)

Plastic 3D reconstructions involve using the skull as a base upon which modelling clay is applied and soft tissues sculpted according to previously determined anatomical relationships (Tyrrell *et al.* 1997). A standard method for creating 3D facial reconstructions has not been widely agreed upon, therefore multiple methods and techniques are used. A brief discussion of the variations of the 3D method follows.

2.6.2.1 The morphoscopic method of 3D facial reconstruction

The morphoscopic method, also known as the anatomical or Russian method (De Greef and Willems 2005; Stephan 2006) or Gerasimov's technique (Gatliff and Taylor 2001; Stephan and Henneberg 2001), named after the renowned Russian anthropologist Mikhail M. Gerasimov, uses an anatomical approach to reconstruct the facial muscles, glands, fat and skin (El-Mehallawi and Soliman 2001; Gatliff and Taylor 2001; Kim *et al.* 2005). The first phase of this method involves reconstruction of the head's underlying tissues, muscle by muscle (Taylor 2001), and thereafter sculpting the glands and fatty areas with clay. The skull gives information about the origins and insertions of facial muscles and these muscles indicate prominence and contours necessary to produce a competent reconstruction from a skull (Gatliff and Taylor 2001). The position, direction of pull and approximate strength of these muscles are crucial to the reconstruction process (Prag and Neave 1997; Nelson and Michael 1998). Prosthetic eyeballs are also inserted into the orbits during the technical phase, since the *orbicularis oculi* muscle overlies the top and bottom parts of the eye and cannot be modelled prior to insertion of the eyeball.

The second phase involves modelling the facial mask (Prag and Neave 1997; Wilkinson 2004), which is putting layers of clay over the soft tissues to represent the skin, and adding the nose, eyelids, lips and ears. The sculptor can be guided by generalised rules to the placement and dimensions of facial features (Rogers 1987). Much of the mouth, eyelid and nasal features can be derived from the underlying bony structures (Prag and

Neave 1997), but some parts have no or very little indication in the bone features of the skull (Rogers 1987), thus the remodelling of these features is still a more artistic phase. In short, examples of features derived from the surrounding bone are the nasal profile, which can be derived from information from the nasal bones, maxilla and the brow; the eyelids and eye shape, which can be derived from the nasal root, orbital bone and lacrimal grooves; and the ears, which can be derived from the mastoid process, ramus of the mandible and auditory meatus (Wilkinson 2004). Other features like fatty pads under the eyes, the eyebrows, cheeks and wrinkles, as well as the texture of the skin and other final touches are also added to give a more realistic appearance of the face.

It has been reported that even though Gerasimov's method indeed involved building the temporalis and masseter muscles, the individual smaller muscles were not modelled, but instead average soft tissue depths from the sagittal plane, Frankfurt horizontal plane and five other landmarks were employed (Stephan 2006). These used measurements were not always exact, but adjusted according to the bony morphology displayed by each individual's skull to predict the facial morphology more accurately (Stephan 2006).

The morphoscopic method relied much on critical observation and subjective evaluation (Aulsebrook 2000), but was anatomically very accurate, and thought by many, including Gerasimov himself, to be a more reliable procedure than the method used by Kollman and Büchly who used tissue depth averages for the reconstruction (Conant 2003). Gerasimov wrote the famous memoir *The Face Finder*, published in 1968. Unfortunately Gerasimov's results were not properly recorded, and were highly criticised, but he still reported that he did find much success with his method, and that the more than 150 court ordered forensic cases he was involved with (Starbuck and Ward 2007) could be positively identified using his method (Taylor 2001). Although he was not the first scientist to re-create faces from skulls, he was the first to use a standard established scientific method. This method has spread across the globe and has been fundamental in reconstructions, such as what pharaohs, the earliest inhabitants of the Americas or, more recently, even Jesus might have looked like (Conant 2003). In 1991 Russian investigators also used the methods to clarify the identities of the remains of the family of the last Tsar (Conant 2003). Gerasimov's work is exhibited in museums in Moscow, Georgia and Uzbekistan.

2.6.2.2 The morphometric method of 3D facial reconstruction

The morphometric method (Figure 2.5), also known as the tissue depth method (Gatliff and Taylor 2001; Stephan 2006), American method (De Greef and Willems 2005; Stephan 2006; Starbuck and Ward 2007) or Gatliff's technique (Stephan and Henneberg 2001) of 3D facial reconstruction, relies greatly on average facial STT (depth) measurements (El-Mehallawi and Soliman 2001; Stephan 2006) which are then plotted on the relevant predefined osteological landmarks by using depth indicators (Wilkinson 2004). The STT measurements include the thickness of the muscle, fatty and connective tissue and skin, altogether calculated as one measurement at a particular bony landmark (Gatliff 1984; Gatliff and Taylor 2001). Vinyl eraser strips or wooden dowels are commonly used as markers, which are cut into specific lengths according to the tissue depths and glued to the relevant landmarks (Aulsebrook 2000; Starbuck and Ward 2007) to represent the average tissue depth at that landmark. The number of markers can vary, depending on the preferences of the artist, but the 21 anthropological landmarks described by Rhine and Campbell (1980) are commonly used (Gatliff and Taylor 2001). These tissue thickness values can be looked up in previously established tables published by various researchers as databases specific to different population groups, ages and sexes. Some databases even include data relevant to different body weights. The reconstructor should consider how the anthropological data contained in the forensic report will influence the facial features. Therefore the forensic artist first needs to consult with a forensic anthropologist (Rhine and Campbell 1980), assess the skull and report, and decide on STT values appropriate to the determined sex, ancestry and age. After reading the report and examining the skull, the researcher should already be able to draw up an idea of the overall shape of the face, nasal projection and width, mouth width, thickness of the lips and eyelid pattern. The influences of sex, race, ageing and stature (Wilkinson 2004) are important factors that must be taken into account, and are therefore still fields with potential for extensive further research.

This method is also described to have the two phases: technical and artistic (Taylor 2001). The technical phase includes skull preparation, applying the depth markers and connecting these markers with strips of clay (Aulsebrook 2000) or plasticine as thick as the marker in that area to create a rough contour map of the surface of the face (Wilkinson 2004). The sculptor must use these dimensions, indicated with the tissue pegs at each point, as guidance rather than his artistic concept of the face form (Rogers 1987). The STT indicators should be connected in ways that represent realistic face contours (Stephan 2006). The strips of clay should gradually change in thickness between the adjacent markers (Aulsebrook 2000), but the shape of the bony structures and a realistic shape of the face should be kept in mind and not lost. Simply connecting the tissue pegs, similar to when drawing a "connect the dots" picture, will not work, since it may result in a face with abnormal shapes and curves. The use of the appropriate STT data will add credibility to the facial reproduction, but the facial reconstructor should not blindly accept any of the data, especially with informed analysis of abnormalities, peculiarities or uniqueness to the skull (Rhine and Campbell 1980).

The second or artistic phase is very similar to the artistic phase of the Russian method, wherein the eyelids and eyebrows, nose, lips, ears and other final features are modelled onto the reconstruction.

Since the reconstructor should keep the general architecture in mind, it suggests that one cannot rely on soft tissue depths alone, but anatomical knowledge is required even if the muscles are not sculpted directly onto the skull (Stephan 2006). Even so, the morphometric method relies less on anatomical knowledge than the morphoscopic method, and is a more schematic and rapid technique, and has therefore become the method of choice for many forensic artists (Gatliff and Taylor 2001). The most modern version of this method is known as the American method (Gatliff and Taylor 2001; Wilkinson 2004), which is currently used in South Africa by forensic artists at the Forensic Science Laboratory (FSL).

Although being called the American method, the practitioners responsible for the origin of this method included Krogman and his colleagues, who were centralised in Germany, not America (Stephan 2006). This method has a long history starting from His' blade probing studies described previously, to the more recent pioneers Suzuki (1948), Rhine and Campbell (1980) and the many researchers of modern times conducting studies on many different population groups, ages and sexes with better techniques and equipment that have progressed along with modern technology.

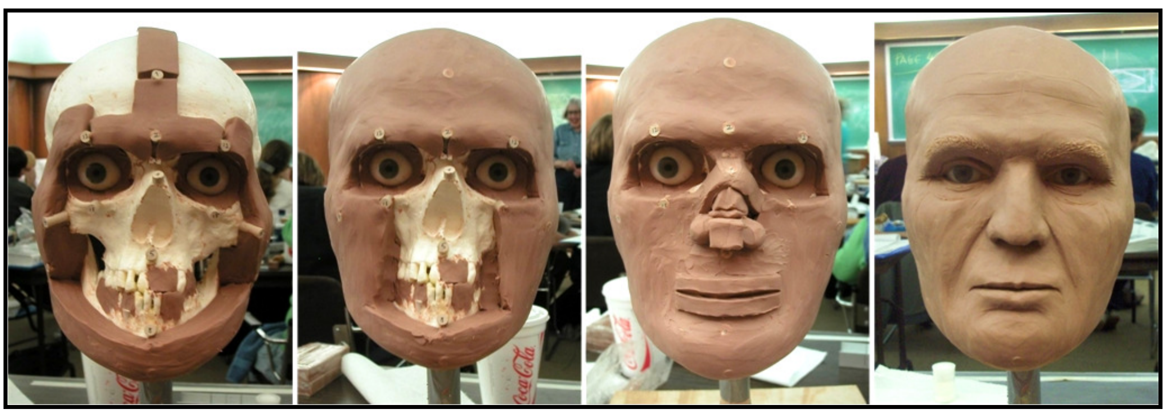

Figure 2.5 An example of the morphometric method of facial reconstruction, where pegs are glued on as tissue thickness indicators, the spaces between the pegs filled with clay and lastly the facial features sculpted (Courtesy of the SAPS)

2.6.2.3 The Manchester method of 3D facial reconstruction

It seems that in the end, all major methods of facial reconstruction depend on both the facial anatomy and average STT values (Stephan 2006). Therefore, many forensic artists use a combination of the two methods previously described. This is known as the Manchester or combination method (Gatliff and Taylor 2001; Wilkinson 2004; Stephan 2006). The Manchester method involves the study of facial anatomy, expression, anthropometry, anthropology and the relationships between hard and soft tissues of the face (Wilkinson 2004).

Again this method is divided into the technical and artistic phases. During the technical phase, the facial musculature is developed, muscle by muscle (Prag and Neave 1997; Gatliff and Taylor 2001) following their origins and insertions. Figure 2.6 indicates the facial muscles that are built up on the skull.

Tissue depth markers are applied on the skull prior to developing the muscles (Figure 2.7), to serve as an advantageous guide to the contours or outline of the face (Snow *et al.* 1970; Gatliff and Taylor 2001). These soft tissue depths need not be strictly adhered to if the morphology of the skull suggests different depths (Stephan and Henneberg 2001). The robustness, size and shape of the landmarks to which the muscles attach (origins and insertions) or over which they lie, also indicate the position, size, shape, thickness or bulkiness of the muscles (Stephan and Henneberg 2001) and therefore contribute to the contours of the face.

The order of the muscles applied as described in the guidelines by Wilkinson (2004) and a simple description of their attachments is as follows: First the *temporalis* muscles are built, from the temporal lines on the upper skull to the mandible. Next the *masseter* muscles are sculpted from the zygomae to the lower border of the ramus of the mandible. Once applied, these two pairs of muscles already start to change the appearance of the bony skeleton (Prag and Neave 1997) and give an indication of the shape of the face when viewed from the front. The *buccinator*, which is basically the cheek muscle, and the *orbicularis oris*, sculpted as a sphincter muscle around the mouth orifice to form the lips, are sculpted next. The width of the mouth slit is roughly determined by the outer borders of the canine teeth (Prag and Neave 1997; Wilkinson 2004). A succession of smaller muscles around the mouth and cheeks, all responsible for conveying facial expression, follows. These include *mentalis*, *depressor labii inferioris*, *depressor anguli oris*, *levator anguli oris*, *levator labii superioris*, *zygomaticus major* and *zygomaticus minor* (Wilkinson 2004). The spaces between these muscles are not empty, but filled with fat, nerves, blood vessels and fascia (Prag and Neave 1997). This is represented by putting little balls of clay into the spaces between the sculpted muscles. If not yet previously done, prosthetic eyeballs are inserted into the orbits, then the *orbicularis oculi* muscle is sculpted, which follows the orbital rim and has a slit or fissure between the upper and lower eyelids (Prag and Neave 1997). The angle of the eye slit can be determined by the bones that form the orbits.

The artistic phase follows (Figure 2.7), wherein all the anatomical modelling is covered up by a layer of clay laid over the surface to simulate the outer layers of subcutaneous tissues and skin (Prag and Neave 1997; Nelson and Michael 1998; Gatliff and Taylor 2001), then the facial features and final touches are added to create the life-like facial appearance. Various literature exists to explain the procedures for sculpting the facial features, with possibly even more literature on the variation of these procedures and their outcomes, but the guidelines from Wilkinson (2004) are amongst the most well known and popular used, especially for the Manchester method.

This method takes advantage of the best aspects of both the morphometric and morphoscopic techniques (Gatliff and Taylor 2001) and ensures that the artist does not and cannot influence the final shape of the face and head, since measurements still rule (Prag and Neave 1997). It is considered to give a very accurate approximation (Wilkinson 2004), but drawbacks to this method include it to be very time consuming, the forensic artist needs to have a good knowledge of the anatomy and osteology of the face (Gatliff and Taylor 2001) and it requires a dedicated period of training and study (Wilkinson 2004).

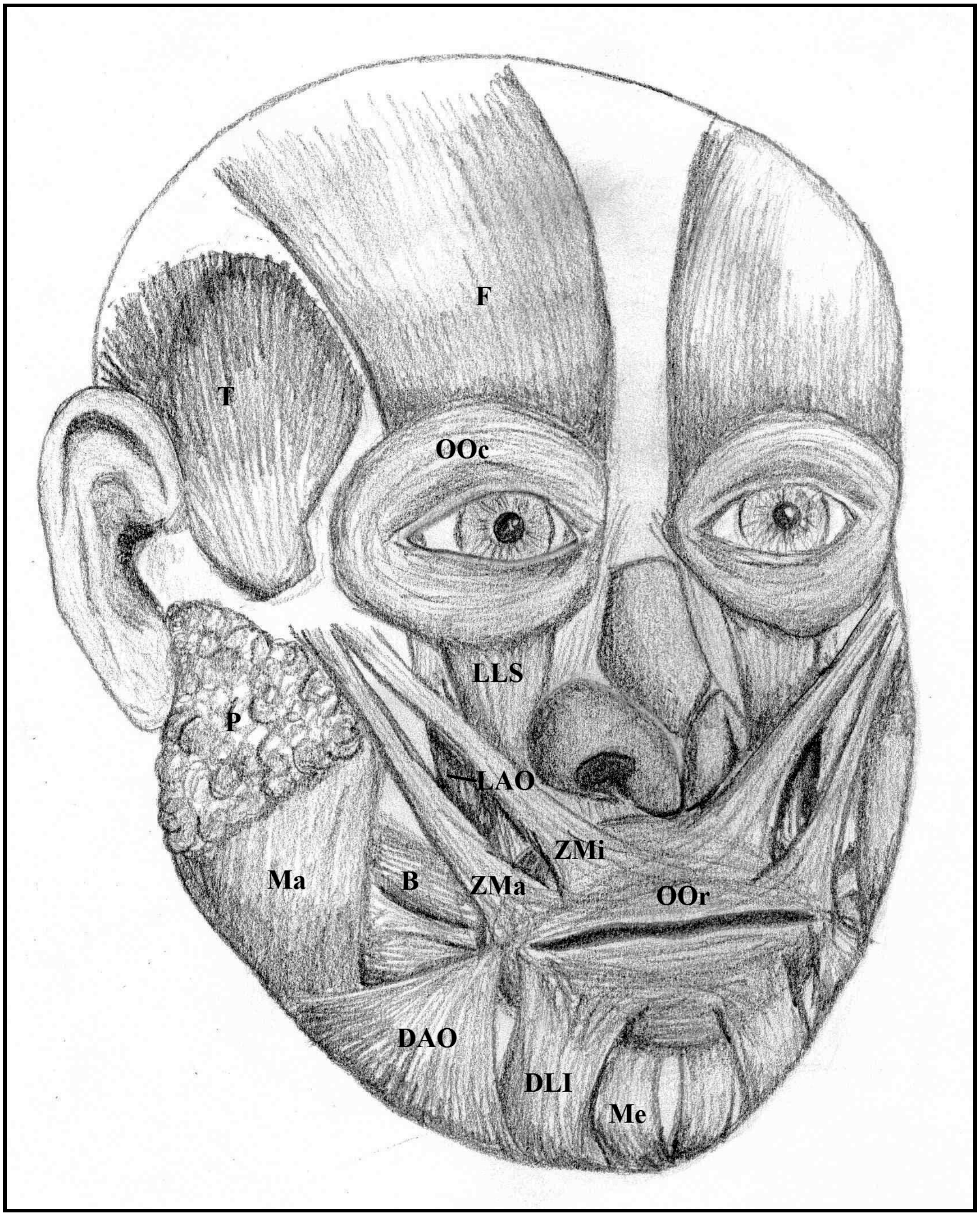

Figure 2.6 Muscles and glands of the face to be reconstructed on a skull. F – Frontalis; T – Temporalis; OOc – Orbicularis Occuli; Ma – Masseter; B – Buccinator; OOr – Orbicularis Oris; LLS – Levator Labii Superiores; LAO – Levator Anguli Oris; DAO – Depressor Anguli Oris; DLI – Depressor Labii Inferiores; Me – Mentalis; ZMa – Zygomaticus Major; ZMi – Zygomaticus minor; P – Parotid Gland

Figure 2.7 An example of the Manchester method of facial reconstruction, with tissue pegs as a tissue thickness indicator, sculpting of the facial musculature and adding layers of clay as the skin, before sculpting the facial features (Courtesy of the SAPS)

2.7 FACIAL IDENTIFICATION / RECONSTRUCTION

2.7.1 Forensic application

In cases where leads to identification are difficult to produce, a face may be modelled directly on a skull with the intended goal to be recognised (Rhine and Campbell 1980) and to help identification of the unknown person (Quatrehomme and İşcan 2000). This technique has been used to good advantage by Clyde Snow and Betty-Pat Gatliff of the Federal Aviation Administration to provide investigators with the reproduction of a face that may be photographed and distributed through the media (Prag and Neave 1997). Although there is some doubt about the efficacy and accuracy of FFR, faces have been reconstructed on skulls for many years with a high degree of success (Rhine and Campbell 1980). Although there is no systematic survey or scientific test, the identification success rate is estimated to be about 50% or better (Quatrehomme and İşcan 2000; George 1987). Some records of success rates of identification of 3D reconstructions, as high as 75% of all cases attempted, have been reported (Manhein *et al.* 2000). These high success rates include that of forensic artists Gerasimov, Suzuki, Gatliff and Snow (1979), Rathbun

(1984), Rhine (1984), Krogman and İşcan (1986), Helmer *et al.* (1993), Prag and Neave (1997) and others.

These success rates indicate that facial reconstructions are at least occasionally identified (Stephan 2003), but this does not indicate accuracy of the reconstructed face or a high resemblance to the actual individual. Successful identification from FFR may be due to factors independent of the modelled face, for example, contextual information, chance, or broadness of media coverage (Stephan 2003). It is important to remember that FFR produces a resemblance to what the face might have looked like. This may be recognised by the public and provide a lead towards identification, but by itself cannot be used as the sole means to establish a positive identification (Rhine 1984). The technique may be used to eliminate certain suspected individuals, or may be useful in helping to support an identification based on other skeletal evidence (Snow *et al.* 1970; Aulsebrook 2000). FFR is a valuable tool to initiate the identification process (Nelson and Michael 1998), but a final positive identification can only be confirmed by conventional techniques, such as radiographic or dental comparisons and DNA analysis (Aulsebrook 2000; Claes *et al.* 2006).

2.7.2 Pitfalls of forensic facial reconstruction

The production of facial reconstructions from skeletal remains is a challenging but interesting aspect of forensic investigation, although it has pitfalls in its application (Rogers 1987). Many problems and difficulties associated with FFR still exist. Throughout its history, and still today, the process and its results have not been without criticism (Rathbun 1984). Facial recognition is already an extremely complicated task, and is also further complicated by the variation exhibited by STT and facial features (Starbuck and Ward 2007).

The smaller or limited number of subjects used in past and existing studies has been questioned, this being whether the subjects are representative of a specific population group (de Greef *et al.* 2006), and may contribute to the considerable variation that is seen in results (Sahni *et al.* 2008). Since the tissue thickness data greatly affects the accuracy of reconstructions, this field is probably the most pressing issue towards facial reconstructions. The applicability of tissue thickness standards and uncertainty about average proportions of distinctive individual features have been questioned (Rathbun 1984). Even though extensive research has been conducted in the field and many research projects are currently running, there are still insufficient tissue thickness data for every population group across the globe. Within the population-specific data, the data available are limited in terms of age, sex and body build. However, Stephan and Simpson (2008) stated that the race differences that do exist (even the differences within population groups) are likely overpowered by the differences caused between different measurement methods. Therefore, linked to the limited tissue thickness data is the lack of a standard method for determining these tissue thickness values and approximating facial features (Reichs and Craig 1998). Using different measurement methods, each with its own advantages, disadvantages and measuring errors, contributes to the variation that occur in STT data, since it affects the magnitude and accuracy of the obtained values, as well as the confidence with which the values can be regarded as accurate (Sahni *et al.* 2008; Stephan and Simpson 2008). There is also no way to tell which method provides the best resemblance of the true STT of humans (Stephan and Simpson 2008). Refinement of the methods, additional data and larger samples, including regional variations, should further support the reliability of the soft tissue values used in reconstructions (Rathbun 1984).

Using the exact age, sex and population-specific data for facial soft tissue depths has been criticised as well, and it has been said that the sample division due to large variation is not of practical importance (Stephan *et al.* 2005; Smith and Throckmorton 2006; Stephan and Simpson 2008). This suggests that the precise tissue thickness is not critical to facial recognition (Smith and Throckmorton 2006) since it is more dependant on the appearance of facial features and its position and ratio relative to each other (De Greef and Willems 2005), because people tend to focus more on these areas when looking at others' faces. It has also been stated that within groups the variance is higher than the difference between groups, therefore sub-categorisation of soft tissue data is of little practical benefit, and it is suggested that the data should rather be assimilated to increase sample sizes to provide a more statistically powerful, yet simplified data set (Stephan *et al.* 2005; Stephan and Simpson 2008).

Being related to art, another problem that remains is the subjective nature of the practice (Nelson and Michael 1998; Claes *et al.* 2006). This refers to the subjective determination of the facial features and the subjective interpretation of the skull itself (Stephan and Henneberg 2001). Stephan (2003) criticised the accurate prediction of the facial muscles from the skull alone. He stated that it is right for practitioners to realise that the muscles of the face appear to be a significant feature to predict, since it makes up the largest portion of the face and has the strongest association with the skull. However, not all of these have bony attachments, but some originate and insert on other soft tissues, therefore making muscle determination subjective and practically unjustifiable (Stephan 2003).

Even though guidelines exist, much of the characterising facial anatomy is unaccounted for and left up the intuition of the practitioner (Stephan 2003). Therefore, sculpting the facial features and final touches on a reconstruction is very dependent on the anatomical knowledge, experience, feel and technique of the artist rather than on rules (Aulsebrook 2000). The replicability of facial reconstruction has been questioned on the basis of variations in the artistic skills of individual workers (Rathbun 1984). The existence of multiple guidelines for predicting the same facial feature is problematic since practitioners cannot test all the methods before undertaking a reconstruction, so they have to rely on advice or methods of others for at least some of the prediction guidelines and it is impossible for all these varieties of the guidelines to be correct (Stephan 2003). It is unfortunate that there are no standards agreed upon for these individualising facial characteristics, since these are the features that are most likely to be recalled and recognised by witnesses' family members or the public. Not only are these facial features critical for recognition, but they are the hardest to portray correctly (Rathbun 1984). This inconsistency and lack of a standard method for approximating facial features keep it difficult for FFR to be recognised as a legitimate form of facial identification.

The style and colour of the hair, the shape of the eyebrows and presence of facial hair will have a profound affect of the appearance of an individual (Vanezis *et al.* 1989), but has no indication on the skull alone (Stephan and Henneberg 2001). The most subtle details of the face, like wrinkles, birth marks, blemishes, skin folds, scars, tattoos, the wearing of spectacles or earrings and the shape of the ears, have no skeletal evidence from which appearance can be determined (Vanezis *et al.* 1989; Quatrehomme and İşcan 2000; Starbuck and Ward 2007), but remains a speculative part in facial reconstructions. Owing to all these individual variations, even though the skull greatly determines the general shape and position of the main facial features, it is impossible to reconstruct a correct face 100% accurately (Vanezis *et al.* 2000; Prag and Neave 1997; De Greef *et al.* 2006), and it will only resemble the face that a person may have had in life. Even so, the procedure has value that brings it to be used from time to time (Aulsebrook *et al.* 1995; Rogers 1987), especially since the final goal of FFR should not be reconstruction accuracy, but rather recognition or identification success (Claes *et al.* 2006). The outcome is uncertain in every case, but if the sculpture is done correctly and as accurately as possible within the limitations of the technique, it is usually worth a try (Gatliff 1984) and if it results in an identification, despite being unreliable or working by chance, then it is helpful (Stephan 2003). Inaccuracy in facial soft tissue prediction is inevitable (Stephan 2003), but hopefully as more data become available, techniques and materials refined, reconstructions attempted and factors in recognition tested, progress should be made in validating facial reconstruction as another useful technique for forensic application (Rathbun 1984). Even though a margin of error might be involved in sculpting a reconstruction that incorporates a number of characteristics, it may be highly useful when other identification methods have been to no avail (Rogers 1987).

It is still debated as to whether the success of facial reconstruction casework is due to the accuracy of reconstructed faces or due to other factors such as supporting case descriptions (Stephan and Cicolini 2008). Various researchers and investigators have achieved different levels of success with reconstructed faces. The success of facial reconstruction, that is, the identification rate of the reconstructions, is at least in part dependent on the accuracy of the reconstructed face. If the reconstruction is inadequately produced, the chances of identification may be diminished, or it may lead to a misidentification (Vanezis *et al.* 2000).

Assessing the reliability of facial reconstructions also produces a problem (Vanezis *et al.* 2000). The methods of accuracy assessment are varied, and may be responsible for the dissimilar results reported in literature (Stephan and Henneberg 2006; Stephan and Cicolini 2008). The irregularity of success rates may also reflect the effect of chance on the identification of reconstructions. Stephan and Henneberg (2001) stated that successes may be due to either accurate facial approximation techniques or due to chance. They concluded in their study that it is rare for facial approximations to be sufficiently accurate to allow identification of a target individual above chance.

However, since it only takes the stimulation of one witness to believe they recognise a face from a facial reconstruction, which produces a further lead and a tentative identification (Stephan and Henneberg 2006), FFR may be thought of as a useful technique for identification (Stephan and Henneberg 2001). In the many studies using face pools to determine a target individual from a reconstruction, most target individuals were identified by at least one assessor (Snow *et al.* 1970). This supports the fact that these facial reconstructions could at least be expected to be successfully identified in a forensic environment (Stephan and Henneberg 2001). Also, since it appears that familiar faces are easier to identify than unfamiliar faces (Stephan 2002), the testing procedure using assessors to identify unfamiliar faces may reduce the number of true positive identifications being made, compared to those in a forensic scenario (Stephan and Henneberg 2001). In a forensic context, a member of the public is not presented with an array of unfamiliar faces from which to select, but rather a person is making an identification from memory of a familiar person (Stephan and Cicolini 2008). Actually, analysis of the effectiveness of facial reconstruction depends on the ability of associates to recognise with confidence the subject from the restored sculpture (Rogers 1987) and successful applications rely on people familiar with the target (Turner *et al.* 2006). Also in practice, the success of identification from FFR is very dependent on the publication of photographs of the reconstruction, since the images needs to reach those who knew the deceased (Vanezis *et al.* 2000) who would hopefully recognise or associate the reconstruction with a familiar face, and come forward with more information.

In the face pool studies that have been conducted, the large number of false positive identifications, where non-target individuals were identified, confirms that facial reconstruction should not be used as a definite means to positively identify an individual (Vanezis *et al.* 2000; Stephan and Henneberg 2001; Stephan 2002), but rather as a tentative identification and lead for further investigation (George 1987).

2.7.3 Case studies

Many successful identifications after recognition from a FFR have been reported by researchers and investigators over the years. Case studies like these illustrate the potential of facial reproduction to bring about leads (Rhine and Campbell 1980; Rathbun 1984), and show the effectiveness of the standards developed for STT's and methods of producing facial features. These successful identifications reported include case studies by Snow *et al.* (1970), Gatliff and Snow (1979), Rathbun (1984), Rhine (1984), Prag and Neave (1997), Phillips (2001), Taylor (2001) and Wilkinson (2004). Some of the earliest known successful forensic cases involving facial reconstruction were those done by Mikhail Gerasimov. Prag and Neave (1997) reported many reconstructions, of which some may not have been directly responsible for the recognition, but gave considerable support towards the identification.

In South Africa, from the FSL in Pretoria, an example of a positive identification with the aid of facial reconstruction is that of a skull that was found in the late 1990's. A reconstruction has been made using the Manchester method of facial reconstruction. After publication in the media, the reconstruction was recognised. Photographs of the possible victim were provided, and the positive identity of the victim was confirmed by craniofacial (skull-photo) superimposition (pers. comm. Capt. TM Briers). Figure 2.8 shows the reconstructions and photographs of the individual.

Phillips (2001) reported three cases of positive identification through the facial reconstruction of six unnatural deaths. A comment from the mother of one of the victims was that the sculpture did not look exactly like their daughter, but had a remarkable family resemblance, so much so that it looked exactly like their niece. This shows that a facial

Figure 2.8 The final reconstruction on a skull and photographs of the victim that have been matched to the skull by superimposition to confirm positive identity (Courtesy of the SAPS)

reconstruction cannot be expected to be an exact replica of the person in real life, but does have merit and has yielded remarkable results, including the gratitude of the relatives of the (now identified) victim (Phillips 2001).

2.7.4 The future of facial reconstruction

Facial reconstruction is following a tendency towards the development of computerised methodologies (Miyasaka *et al.* 1995; Quatrehomme *et al.* 1997; De Greef and Willems 2005), whether for the purpose of measuring soft tissues, determining proportions of facial features over the skull, or reconstruction of the face. With the advancement towards 3D modelling programmes, computerised facial reconstruction systems mimic the manual clay modelling methods of facial reconstruction (Wilkinson 2005).

Employing computerised technology has many advantages as well as disadvantages. Of the greatest advantages are the reduction of subjectivity and shortened length of time and experience required for facial reconstruction (Miyasaka *et al.* 1995; Tilotta *et al.* 2009). The first impression that computerised facial reconstruction makes is that it has the advantage of speed and flexibility (Vanezis *et al.* 1989; Nelson and Michael 1998). However, all the computerised facial reconstruction systems require anthropological and computer modelling or animation skills, and are therefore time consuming (Wilkinson 2005). Although at first it will take as much time as a clay model to sculpt a computerised face on a skull, once the reconstructor has mastered the skill, it is hoped that the procedure should be more swift and the time spent on each reconstruction reduced (Quatrehomme *et al.* 1997). Furthermore computerised reconstruction is more flexible and open to manipulation (Nelson and Michael 1998), that is, characteristics such as obesity in the face can be easily altered (Quatrehomme and İşcan 2000). It would become possible to produce large sets of reconstructions that span many possibilities (Turner *et al.* 2006). Multiple possible facial reconstructions could be created from a skull by adjusting the data to various parameters (Claes *et al.* 2006; Vandermeulen *et al.* 2006), fitting several templates (Tilotta *et al.* 2009) or selecting different possible facial components to paste over the same bony framework (Miyasaka *et al.* 1995). However, many 3D modelling systems still require the same amount of time to produce alternate faces and it remains a time consuming task to add colour or texture to a 3D model (Wilkinson 2005).

More advantages of computer-based facial reconstructions include more efficient and rapid skull re-assembly if the skull was fragmented, and remodelling of missing fragments is also significantly easier (Wilkinson 2005). Also, one will be able to move beyond the measurement of tissues from 2D views to more detailed analysis of surface features, topography and contours of the face, harmony of different tissue layers within a face, and how these features vary among individuals and different skeletal structures (Smith and Throckmorton 2006).

Unfortunately there are also some disadvantages, including that computerised technology is expensive, and it would not be as easy in all countries to obtain the software programs, 3D scanners or training necessary for computerised reconstruction. The computerised methods of facial reconstruction will still remain dependent on databases of facial components and tissue thicknesses to produce valid and realistic faces (Miyasaka *et al.* 1995). Various computerised facial reconstructions have been developed, tested and reported to be accurate or successful (Claes *et al.* 2006; Turner *et al.* 2006; Vandermeulen *et al.* 2006), but again there is no one standard method that exist. If computerised facial reconstruction is to become more accepted within the forensic field, it is important that researchers more thoroughly analyse and assess the accuracy, reliability and reproducibility of computer-based systems (Wilkinson 2005).

Considering the advancement in technology, computerised reconstruction remains a hopeful prospect for the future of facial reconstruction, with many promising current studies and room for improvement.

CHAPTER 3: MATERIALS AND METHODS

3.1 DEVELOPMENT OF SOFT TISSUE THICKNESS VALUES

3.1.1 Introduction

The first part of the study is metric in nature, and its aim is to develop soft tissue thickness (STT) values for South African black females. When identifying a person, one must look at specific features that may contribute to the uniqueness of an individual's face. The frontal, three-quarter and lateral profiles seem to be the most descriptive and typical of a person, therefore it is most valuable to take STT measurements in these planes (Aulsebrook *et al.* 1996). This will be the basis on which the choices of the landmarks for measurements will be made. Photographs taken of the reconstructions and photographs used for the identification sessions will also be of frontal, three-quarter and lateral profiles for the same reason.

3.1.2 Materials and methods

CT scans obtained at the Steve Biko Hospital (previously known as the Pretoria Academic Hospital) were used to obtain measurements of STT. At the Steve Biko Hospital, the existing database of stored, scanned images is already very large, with a high percentage of CT scans being of the head region. Large samples of accurate STT measurements can be obtained from this database. Being a public hospital, the majority of patients submitted to this hospital are from the rural areas, and in South Africa the majority of these rural areas are inhabited by the black community. With the added advantage that points can be located with precision and measurements can be taken with accuracy (Rocha *et al.* 2003), it is convenient to utilise the CT scanning procedure as a means of measuring facial STT (Phillips and Smuts 1996) in black female patients. The sample comprised 154 South African females between the ages of 18 and 35 years. They were all patients that were subjected to CT scans at the Steve Biko Hospital for reasons not related to this study. As in the study by Sahni *et al.* (2008), patients with head trauma, fractures, swellings, asymmetries, distortions, malformations or any abnormality that could influence the shape of the face or thickness of the subcutaneous tissues and musculature, were excluded from the sample. Even the administration of a local anaesthetic could distort the tissue through swelling and flaccidity and render the individual unsuitable for measurement (Aulsebrook *et al.* 1996). Unfortunately patient details such as weight and height could not be provided, thus thin and obese subjects were also included in the sample. Emaciation and obesity can obviously influence STT, but it is not the purpose, at this stage of the research, to develop databases specific to different body mass states or to exclude these outliers.

The Student Ethics Committee of the University of Pretoria granted permission for this study to be performed, with the provision that all the patient information obtained during the course of this study will be treated as strictly confidential. Patient numbers were recorded, but will remain the property of the author alone, as this information may be useful for reference in future studies. Data that may be reported in scientific journals would not include any information that can identify any patient and/or student as a participant in this study.

3.1.3 Metric analysis

Metric analysis includes identifying bony landmarks on CT scans and measuring the STT values from a specific landmark to the skin surface.

3.1.3.1 Measurements

Measurements were taken with the Image Tool of the CT scan program Centricity to the nearest tenth of a millimetre. The method of soft tissue measurement was similar to that described by Aulsebrook *et al.* (1996), and was established as follows: a tangential line was drawn to the curve of the outer surface of the bony landmark (line 1 on Figure 3.1). A line was drawn perpendicular to the tangent at the bony landmark, and extended outward to meet the facial profile (line 2 on Figure 3.1). The length of the line from the bone to the junction with the skin surface was regarded as the equivalent STT of that landmark (See also Figure 3.2). See Appendix A for the data capturing sheet on which the measurements were recorded.

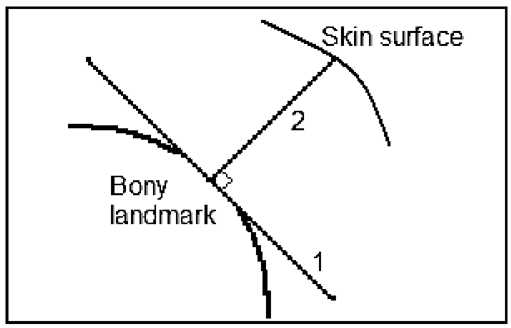

Figure 3.1 Diagrammatic representation of establishing tissue thickness measurements

Figure 3.2 Establishment of STT measurements. This is the measurement of landmark U (area of the parotid). Line 1 is drawn tangential to the greatest curve of the bone and line 2 drawn perpendicular to line 1. At the bottom right corner a Cobb Angle is given between line 1 and 2, in this case 89.9°, to ensure the two lines are at an angle to each other as close to 90° as possible.

3.1.3.2 Landmarks

For this study, 28 biometric landmarks were defined and the tissue depth at each of these landmarks was measured on the CT scans. The locations correspond to the osteological landmarks. Midline landmarks were measured on a topogram view of the CT scans (Figure 3.3 A). The landmarks that fall on the three-quarter or lateral profiles were, by anthropometric convention, measured on the left side of the face on horizontal slide with transverse views from the CT scans (Figure 3.3 B). Some of these landmarks are used traditionally in forensic facial reconstruction (FFR) and were previously defined by Kollmann and Büchly (1898) and Suzuki (1948). Other landmarks are some that were previously defined by Aulsebrook *et al.* (1996). A few landmarks were newly defined by the author as there are other areas on the face that no data are published on, but which could have an influence on FFR. For example, the South African black population group in general has prominent or protruding lips, but the existing STT data indicates thickness of lips over the alveoli of the teeth and not over the teeth, therefore extra measurements in these areas could be useful. Different researchers use different names for the same point, but for the purposes of this study, the various names and definitions have been combined for reasons of clarity. The landmarks are listed and definitions summarised in Table 3.1, and are also indicated in Figures 3.4 and 3.5.

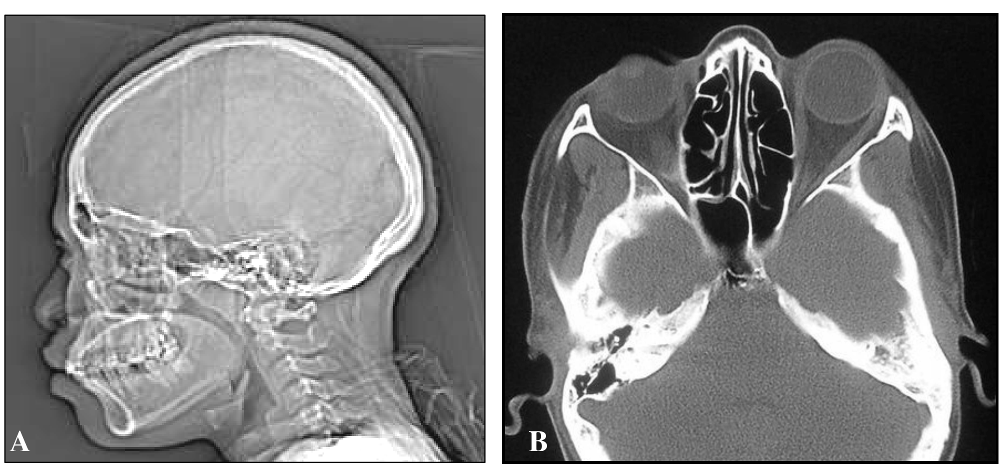

Figure 3.3 A: Topogram view of a CT scan. B: A typical horizontal slice view from a CT scan

Table 3.1 Defined landmarks for measurements and location of tissue depth markers. The landmarks A to M, except F and G, are midline landmarks, and will therefore only be measured once, but landmarks N to Z are bilateral and will, by anthropometric convention, be measured on the left side of the face.

	Landmark	Definition
A #	**Supra-glabella**	Above the glabella
B #	**Glabella**	Most prominent point between supra-orbital ridges in midsagital plane
C #	**Nasion**	Midpoint of the suture between the frontal and the two nasal bones
D #	**End of Nasals** (Rhinion)	Anterior tip of the nasal bones, on the internasal suture
E °	**Lateral Nasal**	A point on the side of the bridge of the nose in line with the endocanthion, or inner corner of the eye
F *	**Lateral Supra-labiale** (Supra canine)	A point on the maximum bulge of the maxillary/upper canine eminence
G *	**Mental Tubercle**	Most prominent point on the lateral bulge of the chin mound
H #	**Mid-philtrum** (Subspinale)	Midline of the maxilla, placed as high as possible before the curvature of the anterior nasal spine begins
I #	**Mid Upper Lip Margin** (Supradentale or Alveolare)	Centered between the maxillary (upper) central incisors at the level of the cementum-enamel junction
II °	**Upper Incisor**	Halfway down the height of the enamel of the upper central incisors
J #	**Mid Lower Lip Margin** (Infradentale)	Centered between the mandibular (lower) central incisors at the level of the cementum-enamel junction
JJ °	**Lower Incisor**	Halfway down the height of the enamel of the lower central incisors
K #	**Supramentale** (Mid Labiomentale or Chin-lip Fold)	The deepest midline point of indentation on the mandible between the teeth and the chin protrusion
L #	**Mental Eminence** (Pogonion or Anterior Symphyseal)	The most anterior projecting point in the midline on the chin
M #	**Beneath Chin** (Menton)	The lowest point on the mandible
N #	**Frontal Eminence**	A point on the projections at both sides of the forehead
O *	**Fronto-temporale**	The most medial point on the curve of the temporal ridge, on the frontal bones, above the zygomaticofrontal suture
P #	**Supra-orbital**	Above the orbit, centered on the uppermost margin of the orbit
Q #	**Sub-orbital**	Below the orbit, centered on the lowermost margin of the orbit
R *	**Zygomaxillare**	Lowest point on the suture between the zygomatic and maxillary bones
S *	**Lateral Zygomatic Arch** (Zygion)	A point on the maximum lateral outer curvature of the zygoma
T #	**Supra-glenoid**	Above, and slightly forward of the external auditory meatus
U °	**Area of the Parotid**	A midline point between the external auditory meatus and point V (mid-masseteric)
V *	**Mid-masseteric**	A point at the centre of an area bounded by the lower borders of the zygomatic arch and mandible, anterior fibers of the masseter muscle and posterior border of the ascending ramus of the mandible
W #	**Gonion**	The most lateral point on the mandibular angle
X #	**Supra M^2**	Above the second maxillary molar
Y #	**Sub M_2**	Below the second mandibular molar
Z #	**Occlusal Line**	On anterior margin of the ramus of the mandible, in alignment with the line where the teeth occlude or "bite"

Landmarks defined by Rhine and Campbell (1980) for measurements or location of tissue depth markers
* Landmarks defined by Aulsebrook *et al.* (1996) for measurements or location of tissue depth markers
° Newly defined landmarks for measurement or location of tissue depth markers

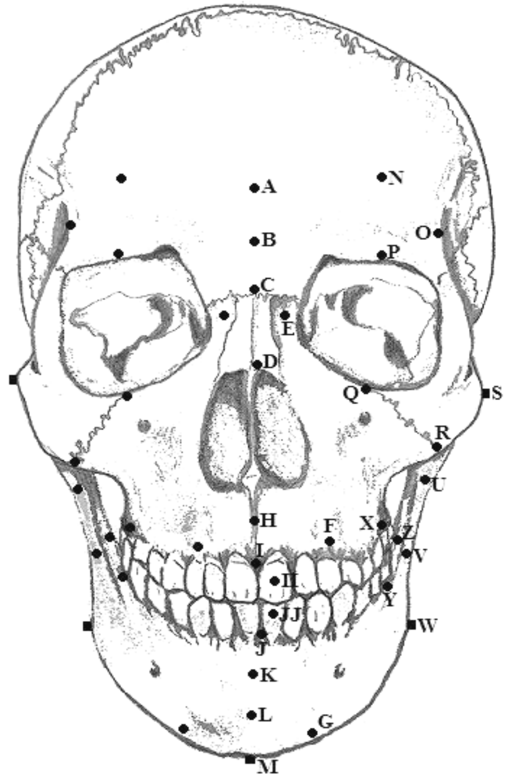

Figure 3.4 Frontal view landmarks for measurements or location of tissue depth markers
The landmarks are described in Table 3.1

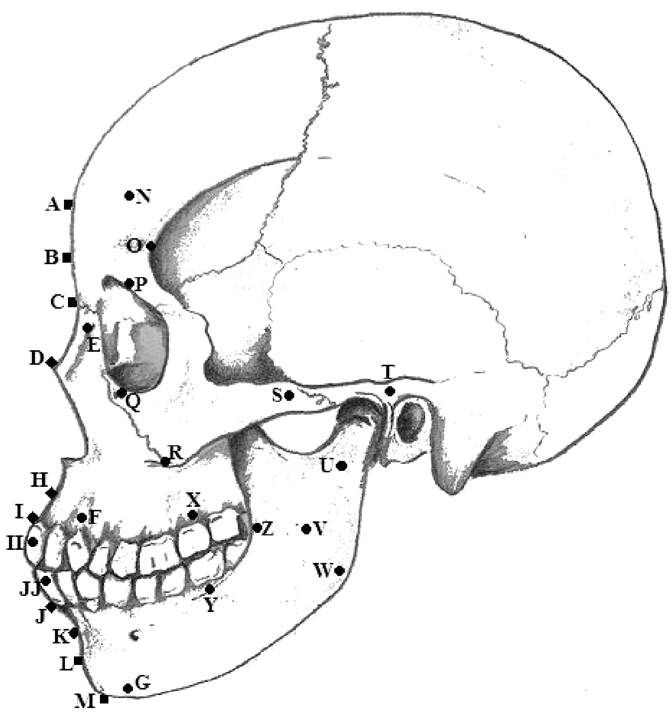

Figure 3.5 Lateral view landmarks for measurements or location of tissue depth markers
The landmarks are described in Table 3.1

The detailed descriptions of the landmarks indicated in Figures 3.4 and 3.5 as well as a description on how these were measured are as follows:

A – Supra-glabella

A point above the glabella, or more specifically a point above the depression between the glabella and frontal eminence, or if there is no dip, a point where the curvature of the frontal eminence starts (Phillips and Smuts 1996) (Figure 3.6). The point is also described as the most anterior midline point of the forehead (Rhine and Campbell 1980; Wilkinson 2004; De Greef *et al.* 2006).

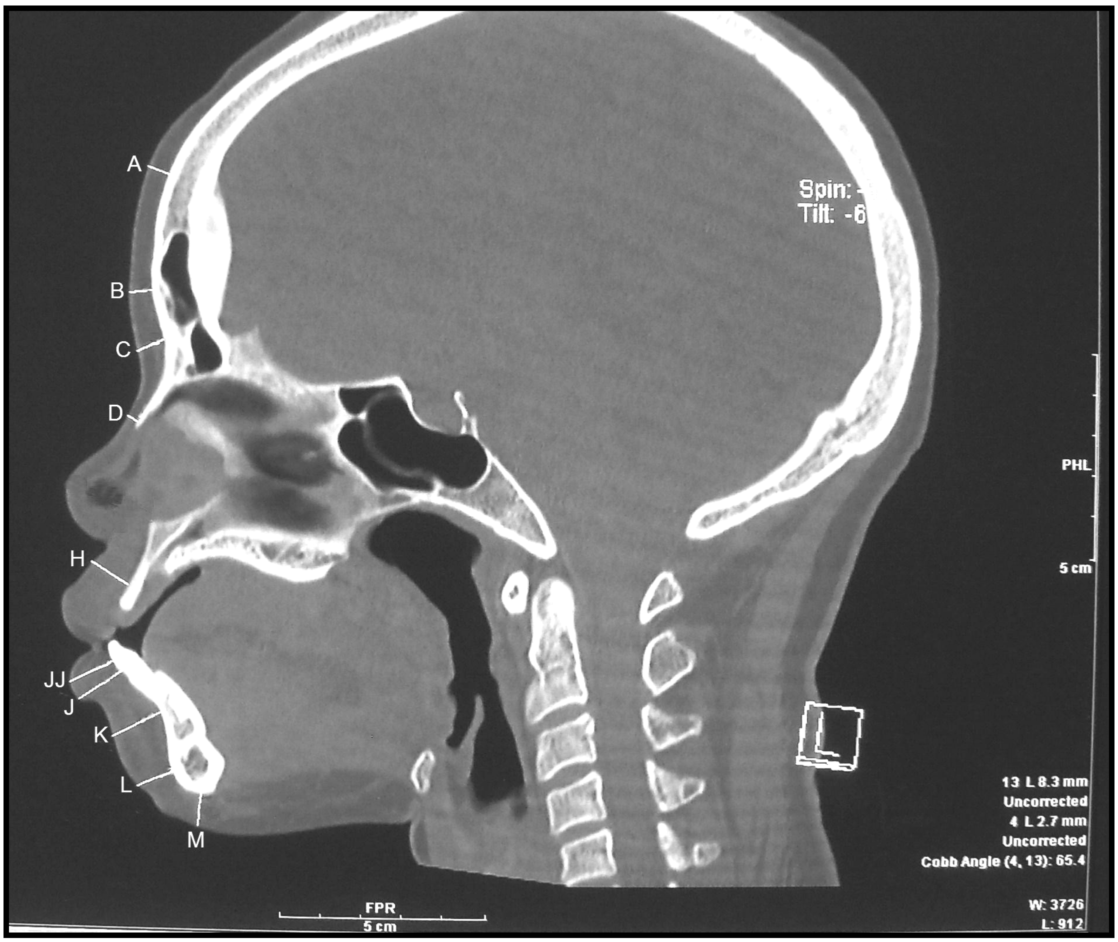

Figure 3.6 A topogram indicating the position of the midline measurements.
A – Supra-glabella; B – Glabella; C– Nasion; D – End of nasals; H – Mid-philtrum;
J – Mid lower lip margin; JJ – Lower incisor; K – Supra-mentale; L – Mental eminence;
M – Beneath chin

B – Glabella

The most prominent point, or most anterior convexity, between the supra-orbital ridges in the midsaggital plane (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996; Wilkinson 2004) (Figure 3.6).

C – Nasion

The midpoint on the frontonasal suture (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996; Wilkinson 2004; De Greef *et al.* 2006) (Figure 3.6).

D – End of nasals

The anterior tip of the furthest point on the nasal bones, on the internasal suture, also known as the rhinion (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996; Manhein *et al.* 2000) (Figure 3.6).

E – Lateral nasal

A point on the side of the bridge of the nose, horizontally in line with the inner canthus of the eye (De Greef *et al.* 2006). The measurement was taken on the left side of the horizontal slide of the CT scan, where the orbits were at their greatest breadth (Figure 3.7).

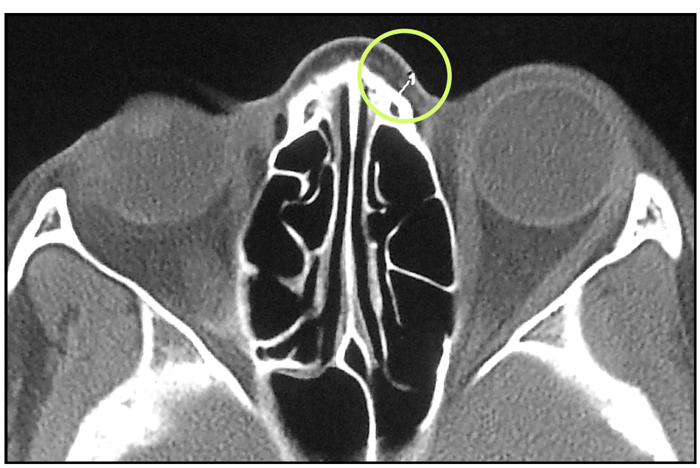

Figure 3.7 Position of the lateral nasal measurement

F – Lateral supra-labiale

A point on the maximum bulge of the maxillary canine eminence (Aulsebrook *et al.* 1996). The point is also known as the supra-canine (Manhein *et al.* 2000; De Greef *et al.* 2006). The point was measured on the highest horizontal slide where the bone covering the alveoli is still visible (Figure 3.8).

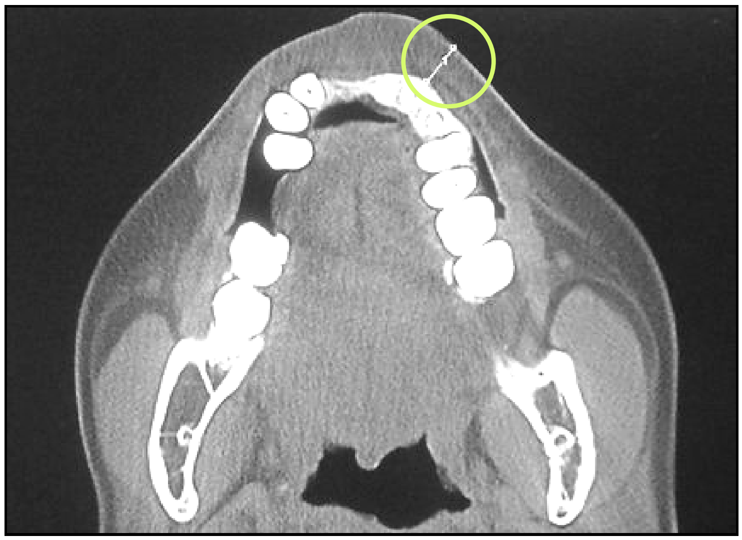

Figure 3.8 Position of the lateral supra-labiale measurement

G – Mental tubercle

A landmark measured on the most prominent point on the lateral bulge of the chin mound (Aulsebrook *et al.* 1996; De Greef *et al.* 2006) (Figure 3.9).

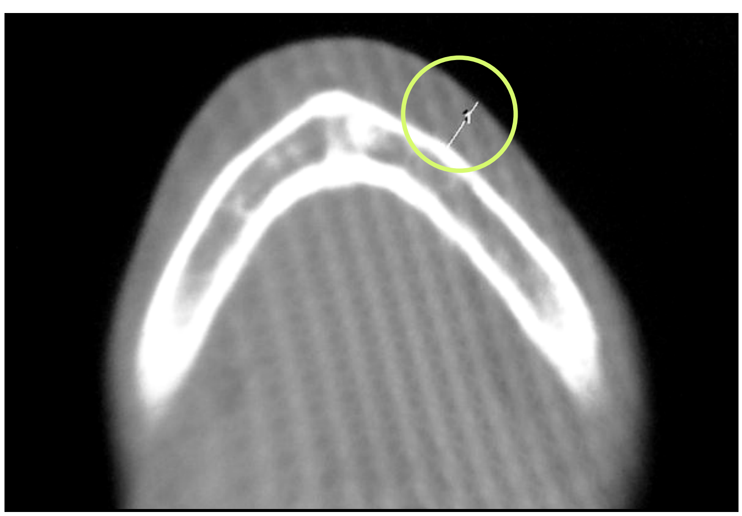

Figure 3.9 Position of the mental tubercle measurement

H – Mid-philtrum

A point in the midline of the maxilla, placed halfway between where the alveolus of the incisor and the curvature of the anterior nasal spine begins, also called the subspinale or subnasale (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996; Wilkinson 2004) (Figures 3.6 and 3.10).

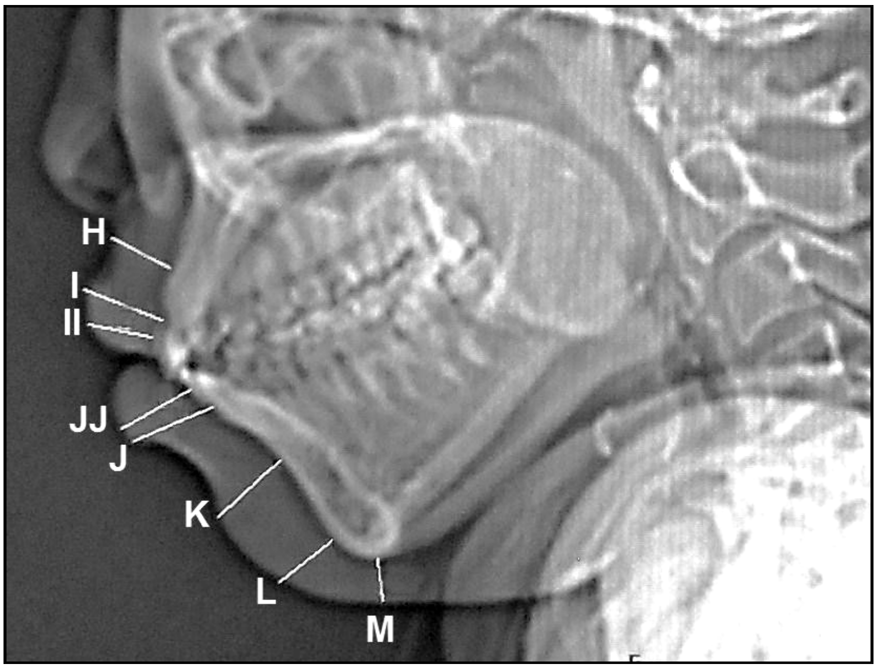

Figure 3.10 A section of a topogram indicating some midline measurements.
H – Mid-philtrum; I – Mid upper lip margin; II – Upper incisor; J – Mid lower lip margin; JJ – Lower incisor; K – Supra-mentale; L – Mental eminence; M – Beneath chin

I – Mid upper lip margin

A point centered between the maxillary central incisors at the level of the cementum-enamel junction, also known as the supradentale or alveolare (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996) (Figure 3.10).

II – Upper incisor

A point newly defined for this study. It is halfway down the height of the enamel of the upper central incisors (Figure 3.10).

J – Mid lower lip margin

A point centered between the mandibular central incisors at the level of the cementum-enamel junction, also known as infradentale (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996) (Figures 3.6 and 3.10).

JJ – Lower incisor

A point newly defined for this study. It is a point halfway down the height of the enamel of the lower central incisors (Figures 3.6 and 3.10).

K – Supra-mentale

The deepest midline point of indentation on the mandible between the teeth and the chin protrusion (Figures 3.6 and 3.10), also known as sublabiale, mid-labio-mental or the chin-lip fold (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996; Wilkinson 2004; De Greef *et al.* 2006).

L – Mental eminence

The most anterior projecting point in the midline on the chin (Wilkinson 2004; De Greef *et al.* 2006), or the maximum forward curvature of the mental prominence (Figures 3.6 and 3.10), also called pogonion or anterior symphyseal point (Aulsebrook *et al.* 1996).

M – Beneath chin

The lowest medial landmark, at the lowest point on the curve of the body of the chin (Figures 3.6 and 3.10) (Rhine and Campbell 1980; Wilkinson 2004; Aulsebrook *et al.* 1996), also known as the menton, bony gnathion (Wilkinson 2004) or inferior symphyseal point (Aulsebrook *et al.* 1996).

N – Frontal eminence

A point on the projections at both sides of the forehead, on the lateral frontal bone, lateral to the supra-glabella and directly above the midpoint of the eyebrow (Rhine and Campbell 1980; Wilkinson 2004) (Figure 3.11).

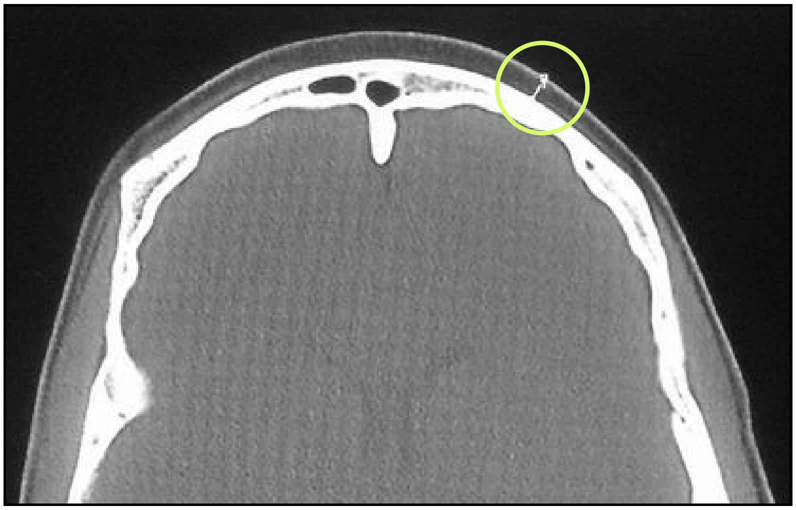

Figure 3.11 Position of the frontal eminence measurement

O – Fronto-temporale

The most medial point on the curve of the temporal ridge, on the elevation of the temporal lines on the frontal bones, above the zygomaticofrontal suture (Aulsebrook *et al.* 1996; Wilkinson 2004) (Figure 3.12).

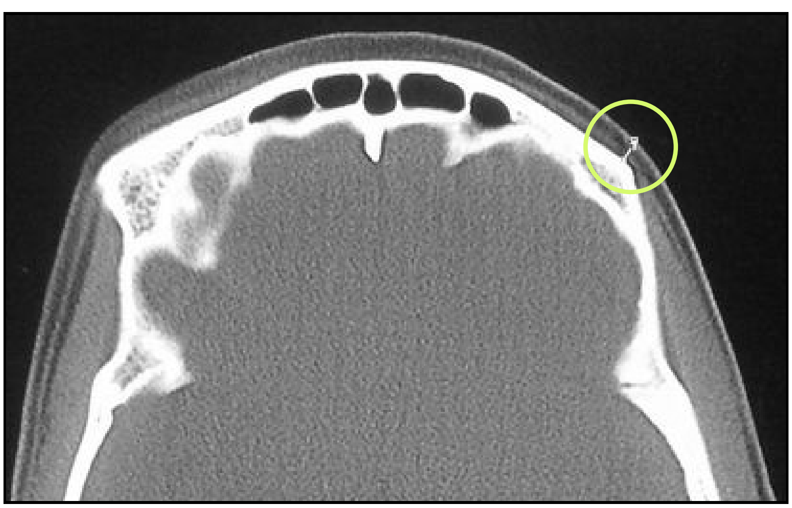

Figure 3.12 Position of the fronto-temporal measurement

P – Supra-orbital

A point above the orbit, centered on the uppermost margin or border of the orbit (Rhine and Campbell 1980; Wilkinson 2004). This measurement was taken on the horizontal slide on the CT scans just above the last slice where the orbit was still open (Figure 3.13).

Figure 3.13 Position of the supra-orbital measurement

Q – Sub-orbital

A point below the orbit, centered on the lowermost margin or border of the orbit (Rhine and Campbell 1980; Wilkinson 2004). This measurement was taken on the horizontal slide on the CT scans just below the first slice where the orbit starts to appear open (Figure 3.14).

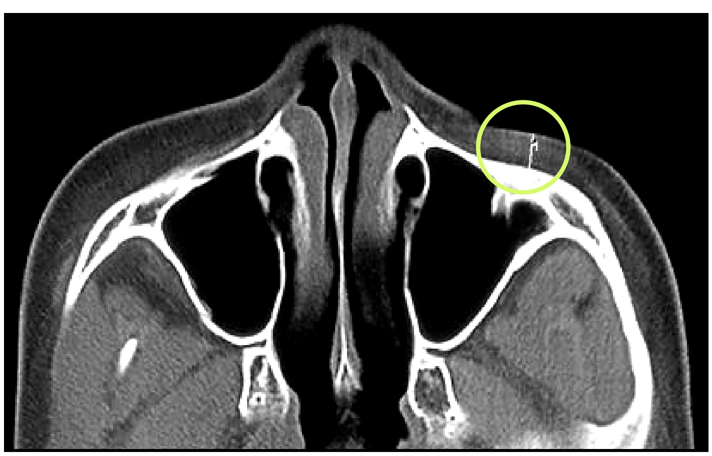

Figure 3.14 Position of the sub-orbital measurement

R – Zygomaxillare

The lowest point on the suture between the zygomatic and maxillary bones (Aulsebrook *et al.* 1996), also known as the inferior malar point (Rhine and Campbell 1980; Phillips and Smuts 1996). The measurement was taken at a point where the zygomatic bone meets the maxilla (Figure 3.15).

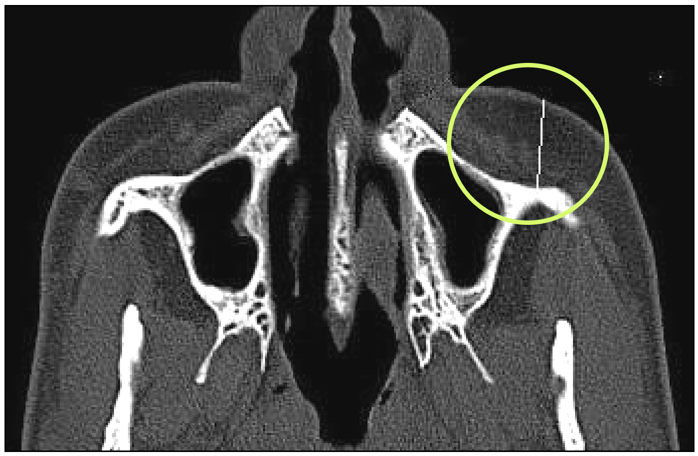

Figure 3.15 Position of the zygomaxillare measurement

S – Lateral zygomatic arch

A point on the maximum lateral outer curvature of the zygomatic bone, also known as the zygion (Rhine and Campbell 1980; Aulsebrook *et al.* 1996; Phillips and Smuts 1996; Wilkinson 2004; De Greef *et al.* 2006) (Figure 3.16).

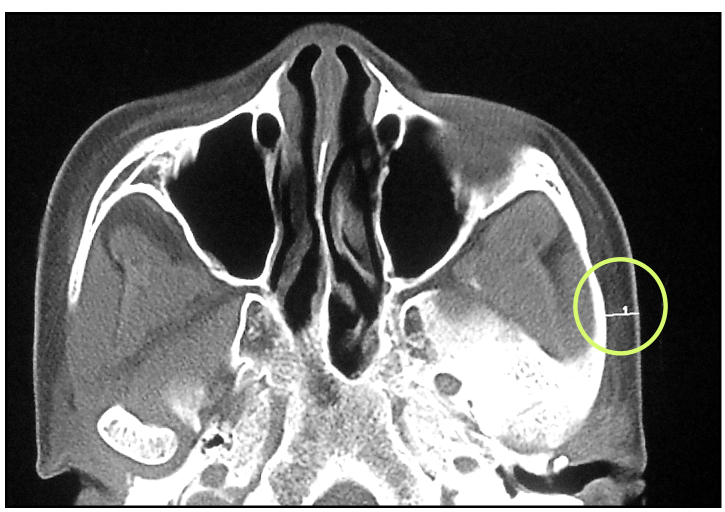

Figure 3.16 Position of the lateral zygomatic arch measurement

T – Supra-glenoid

A point above and slightly forward of the external auditory meatus (Rhine and Campbell 1980). It is a point just anterior to a point called the porion, defined as the highest point on the upper margin of the external auditory meatus (Wilkinson 2004). The measurement was taken on the CT scan slide just above where the external auditory meatus last appeared open (Figure 3.17).

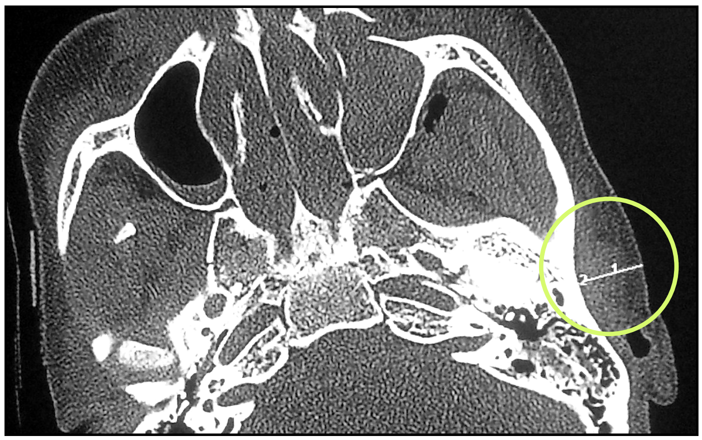

Figure 3.17 Position of the supra-glenoid measurement

U – Area of the parotid

A point newly developed for this study, below the condyle on the ramus of the mandible. The measurement was taken on the horizontal CT scan slide just before the ramus shows the split between the condylar and coronoid processes (Figure 3.18).

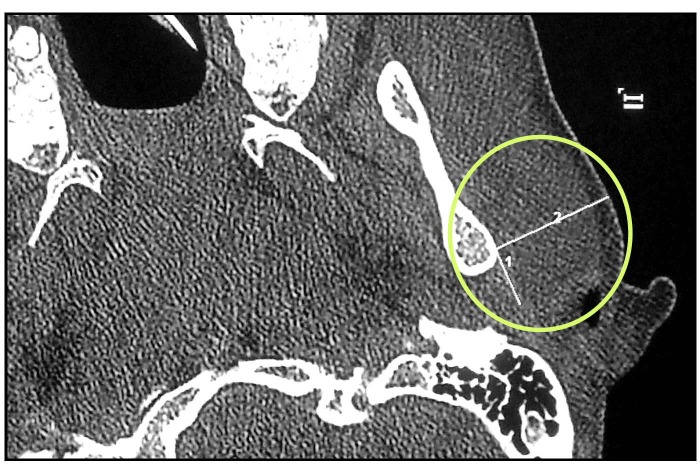

Figure 3.18 Position of the measurement for the area of the parotid

V – Mid-masseteric

A landmark lying in the centre of an area bounded by the lower borders of the zygomatic arch and mandible, and anterior and posterior borders of the ascending ramus of the mandible (Aulsebrook *et al.* 1996). It is also described as the halfway point between the supra-glenoid and the gonion (De Greef *et al.* 2006). The measurement was taken on the horizontal CT slide where the mandibular ramus has the flattest appearance (Figure 3.19).

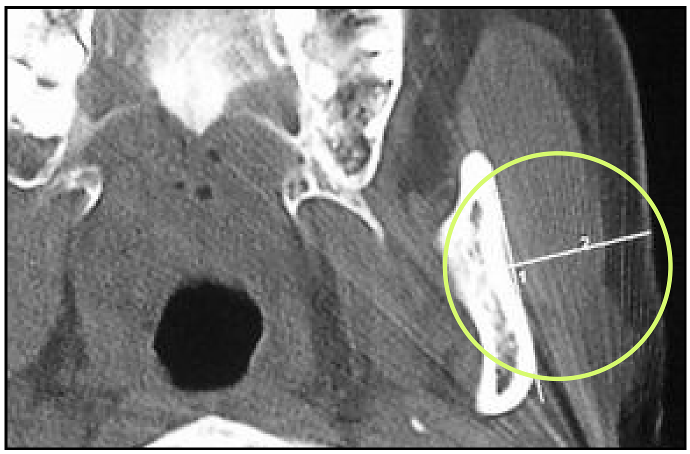

Figure 3.19 Position of the mid-masseteric measurement

W – Gonion

The most lateral point on the mandibular angle (Rhine and Campbell 1980; Wilkinson 2004; De Greef *et al.* 2006). The measurement was taken on a coronal CT scan at the most posterior slide where the ramus of the mandible is still visible (Figure 3.20).

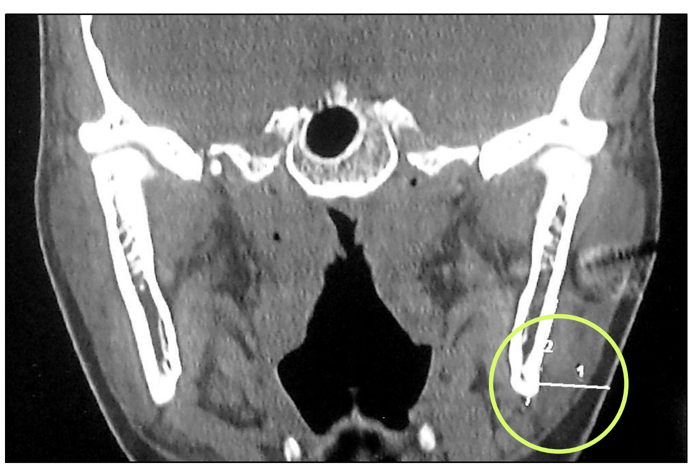

Figure 3.20 Position of the gonion measurement

X - Supra M^2

A landmark above the second maxillary molar (Rhine and Campbell 1980; Phillips and Smuts 1996). The measurement was taken on a horizontal CT scan slide where the bone covering the alveoli of the second maxillary molar just appears (Figure 3.21).

Figure 3.21 Position of the supra-maxillary-second-molar measurement

Y - Sub M_2

A landmark below the second mandibular molar (Rhine and Campbell 1980; Phillips and Smuts 1996; De Greef *et al.* 2006). This measurement was taken on a horizontal CT scan slide where the bone covering the alveoli of the second mandibular molar just disappears (Figure 3.22).

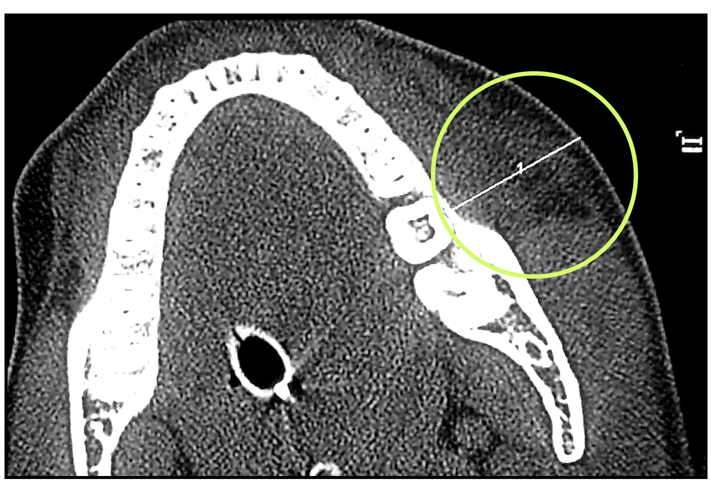

Figure 3.22 Position of the sub-mandibular-second-molar measurement

Z – Occlusal line

A point on the anterior margin of the ramus of the mandible, in alignment with the line where the teeth occlude or "bite" (Rhine and Campbell 1980). Wilkinson (2004) has described this point as the midmasseter point, where a line is extended along the occlusal line to the centre of the ramus of the mandible. The measurement was taken on a horizontal CT scan slice where the occlusal surfaces of the upper and lower molars just disappeared, from the most anterior point on the ramus of the mandible where a line can be drawn outward towards the skin surface (Figure 3.23).

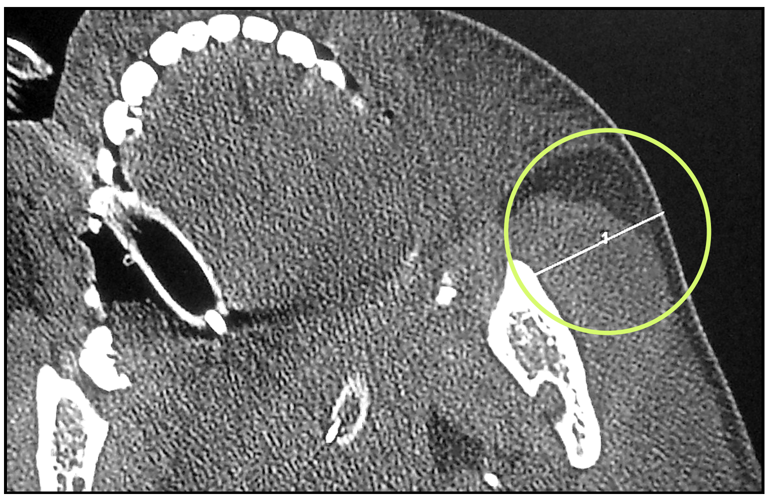

Figure 3.23 Position of the occlusal line measurement

3.1.4 Tests of repeatability

In order to confirm the accuracy and repeatability of the measurements, the measurements of 22 individuals were repeated by the investigator at a different time, and measurements of 29 individuals were repeated by an independent observer.

3.1.5 Statistical analysis

The basic descriptive statistics, namely the mean, range and standard deviation, were calculated for each measurement. The means of the measurements were used as the STT values for the reconstruction part of the study. The mean of each value was compared to that of databases for black females from the USA developed by Manhein *et al.* (2000), the revised tables from Rhine and Campbell (1980) as well as a database for females of mixed racial origin, developed by Phillips and Smuts (1996). These were compared by means of a Student's *t*-test, in order to assess whether significant differences exist in any of the values between the population groups. The inter- and intra-observer repeatability between the original and second set of measurements was assessed by means of the intra-class correlation coefficient, which reflects good repeatability when the value is closer to one (Allan 1982; Ferrante and Cameriere 2009). The above-mentioned statistical analyses were done with the help of Prof PJ Becker, statistician at the Medical Research Council (MRC). To further assess the means of the measurements for the repeatability tests, the Student's *t*-test was also used. For the identification sessions, the Chi-squared test was used to determine whether the identification rates and likeness rates of the reconstructions were above chance.

3.2 TESTING THE ACCURACY OF THE NEWLY DEVELOPED SOFT TISSUE THICKNESS VALUES

3.2.1 Introduction

When a pharmaceutical company has developed a new drug, it cannot take for granted that it will work before the drug has been tested for its effects and side-effects. In the same way, one cannot just believe that the newly developed measurements are accurate and could lead to an accurate, recognisable reconstruction, or that they could perform any better than values published for a different population group. Therefore, these measurements have been put to practical test in order to determine the accuracy and recognisability of the reconstructions produced from them.

3.2.2 Facial reconstructions

Testing the accuracy of facial reconstructions is problematic, since an antemortem photograph of the individual is seldom available for comparison. However, a unique opportunity arose when the FSL of the South African Police Service in Silverton, Pretoria, made skulls and photographs available, of two female individuals between the ages of 18 and 30 years, for this type of study. The skulls are from actual forensic cases that had since been identified by other means, such as craniofacial superimposition. Therefore reconstructions could be made on these skulls and compared with the photographs to determine the accuracy of the reconstructions.

Permission was granted by the FSL to produce plaster replicas of the skulls. Three different previously published databases by three different groups of researchers were chosen from which reconstructions were produced in order to compare the outcome of reconstructions on the same skull when reconstructed from different tissue thicknesses based on data from different population groups. These databases included a study by Rhine and Campbell (1980) on 15 black females from the USA, a study by Manhein *et al.* (2000) on 18 black females from the USA, and a study by Phillips and Smuts (1996) on 16 mixed race females from South Africa.

A total of eight casts were made, four of each skull, using a technique developed by the staff at the FSL, involving a silicon mould and plaster of Paris (Figure 3.24). For this study, the skulls were labelled Skull A/Individual 1 and Skull B/Individual 2. A total of eight reconstructions were thus made, four of Individual 1 and four of Individual 2, in each case using a different set of STT values.

The investigator did not see the photographs of the individuals who were matched to the skulls before the reconstruction phase of the study was completed to ensure that it was a blind study and that the investigator was not biased by the true specific shapes of the face and facial features of the individuals.

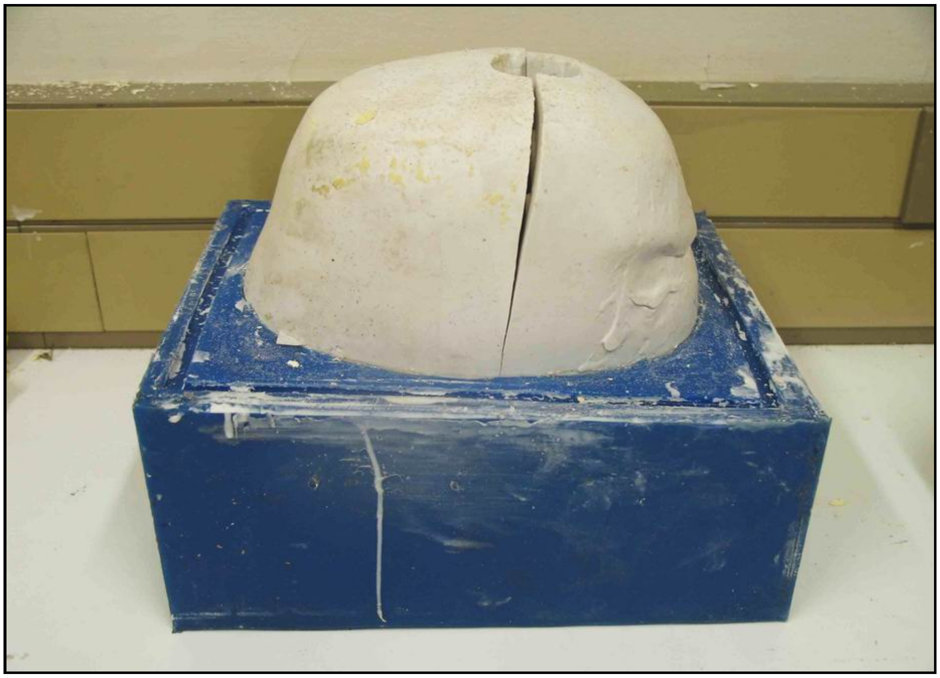

Figure 3.24 Casting a skull using a silicon mould of the original skull, and then pouring plaster of Paris into the mould to make an accurate cast. The blue polyurethane base served as a means to keep the mould in place and to prevent distortion of the mould after the skull had been taken out and the plaster had been poured in.

The Manchester method of facial reconstruction, as described by Wilkinson (2004), was chosen for this study. The investigator had the opportunity to obtain considerable experience with this specific method after she had undergone supervised training by Dr Wilkinson and her colleagues at the University of Dundee, Scotland. Refer to Chapter 2, section 2.6.2 (The methods and techniques of facial reconstruction) for a detailed description of the Manchester method of FFR. Steps for the reconstructions were followed as outlined in Wilkinson (2004). These are demonstrated in Figures 3.25 and 3.26 for the two skulls respectively. Photographs were taken throughout the process of reconstruction. When the final touches on the reconstructions were completed, it was photographed in the Frankfurt horizontal plane in three views, including full frontal, right three-quarter and right lateral profiles for purposes of the identification session.

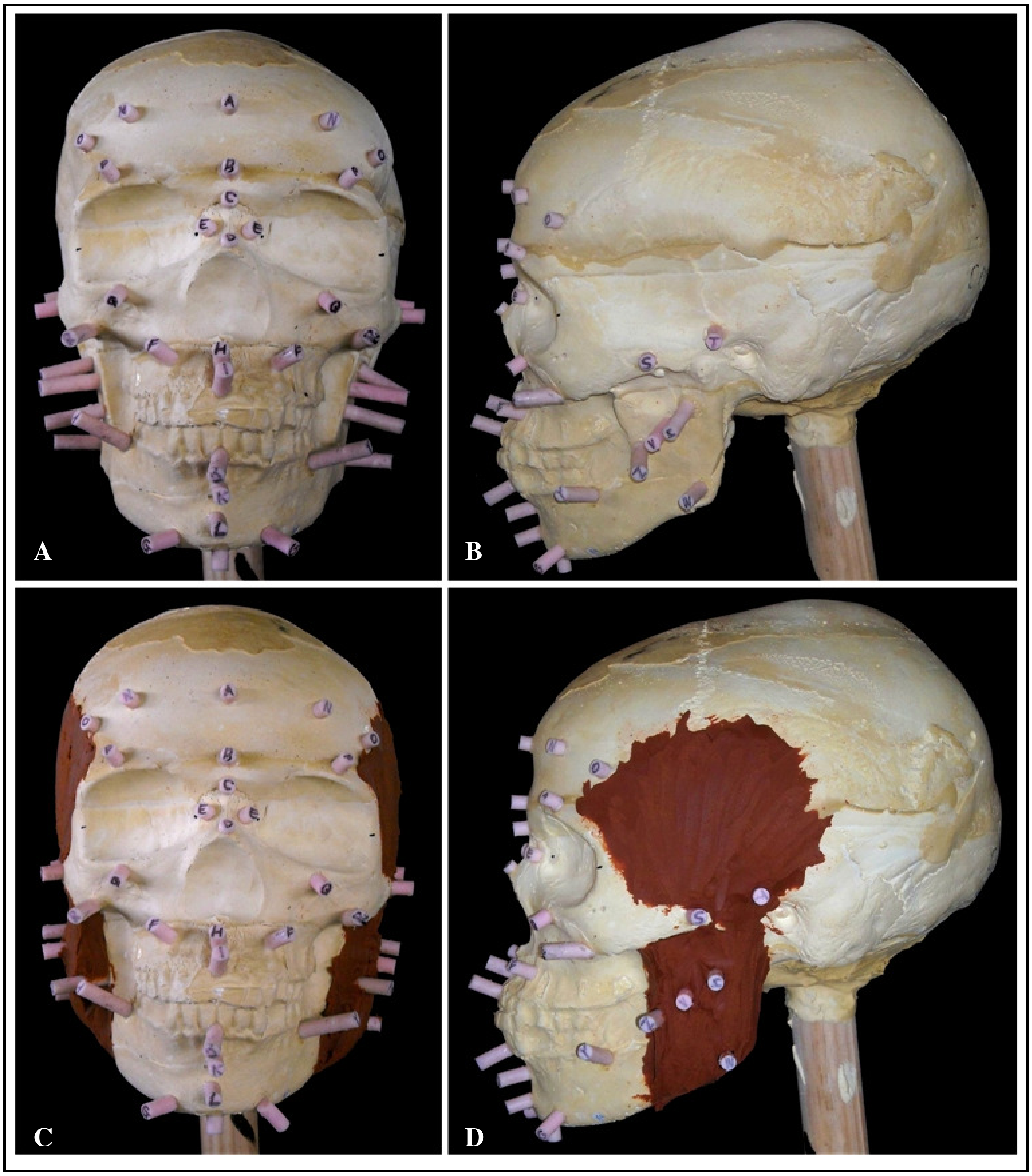

Figure 3.25a Some of the steps of the Manchester method of FFR. This is Skull A/Individual 1 reconstructed with the tissue thicknesses from the newly developed values in this study. A and B indicate the placement of tissue thickness pegs in the frontal and lateral view respectively. C and D show the temporalis and masseter muscles modelled onto the skull

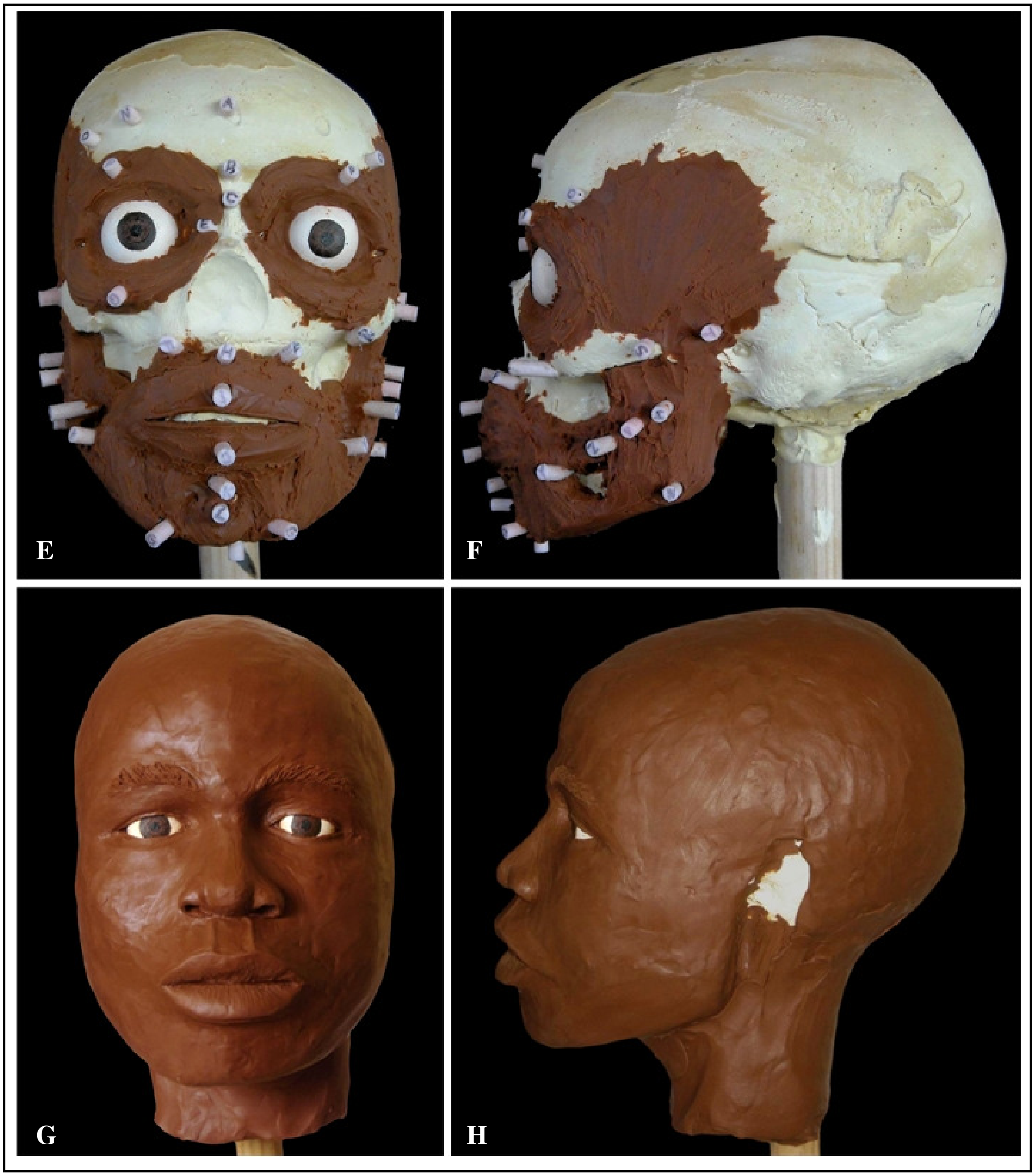

Figure 03.25b Some of the steps of the Manchester method of FFR. This is Skull A/Individual 1 reconstructed with the tissue thicknesses from the newly developed values in this study. E and F show the facial muscles around the mouth and eyes modelled onto the skull, and insertion of the eyeballs. G and H show the reconstruction after the skin, eyelids, eyebrows, nose and lips had been modelled over the soft tissues on the skull

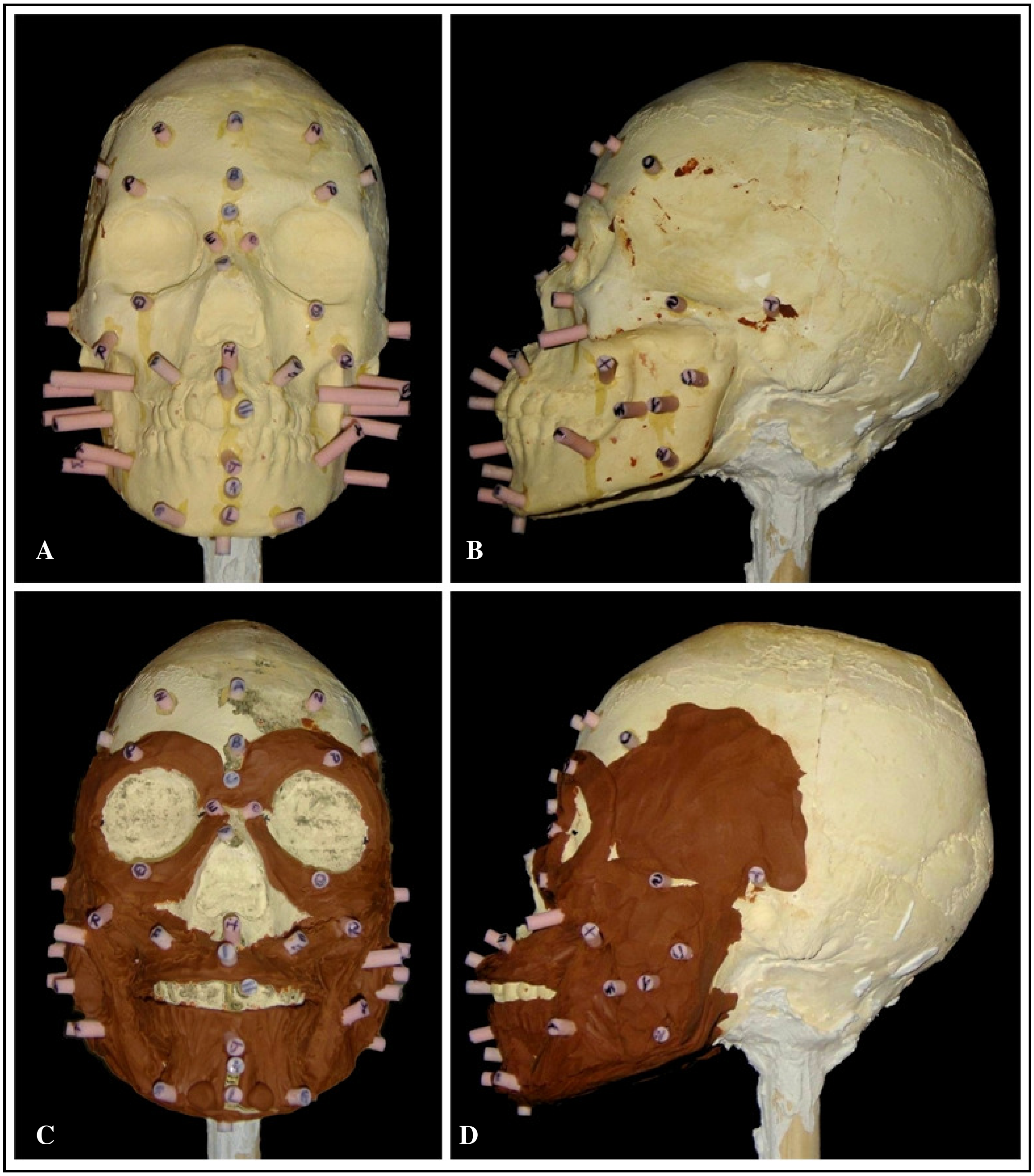

Figure 3.26a Some of the steps of the Manchester method of FFR. This is Skull B/Individual 2 reconstructed with the tissue thicknesses from the newly developed values in this study. A and B indicate the placement of tissue thickness pegs in the frontal and lateral view respectively. C and D show the facial muscles modelled onto the skull

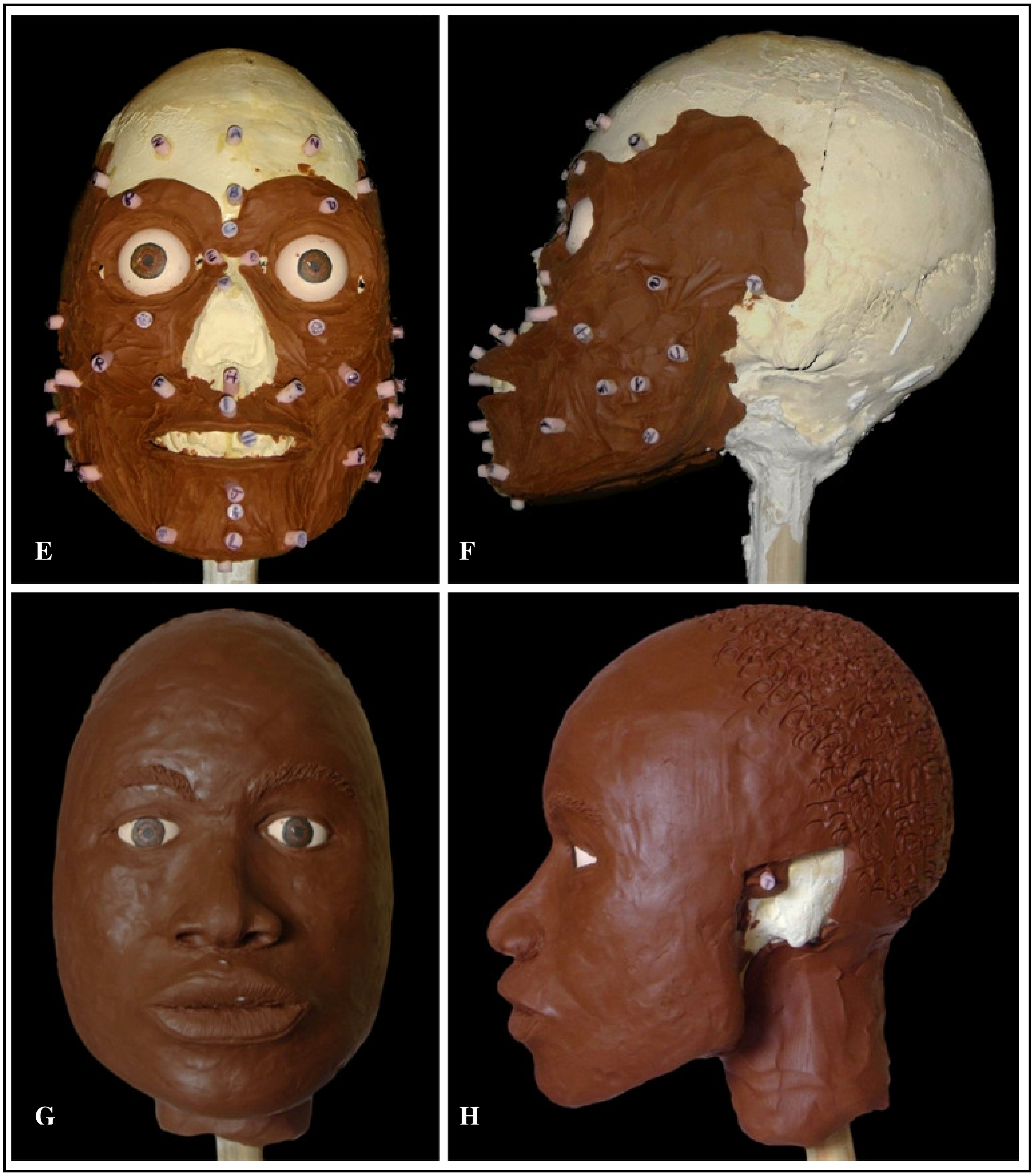

Figure 3.26b Some of the steps of the Manchester method of FFR. This is Skull B/Individual 2 reconstructed with the tissue thicknesses from the newly developed values in this study. E and F show the insertion of the eyeballs. G and H show the reconstruction after the skin, eyelids, eyebrows, nose and lips had been modelled over the soft tissues on the skull

3.2.3 Identification sessions

To assess the success of the reconstructions and therefore also the soft tissue measurements, two identification sessions were set up where photographs and reconstructions were compared with each other.

The first of these identification sessions involved 30 individual observers, with and without a background in medical sciences, who were asked to match various photographs of the black females to each of the eight reconstructions. For this purpose, 18 photographs were recruited from black female students between the ages of 18 and 30 years, who were not taking part in the identification sessions as an observer. The photographs of the volunteers were scanned and edited to look similar in quality to the two photographs matching the skulls, so that none of the photographs would stand out in any way to give any hints of any sort to what the true match to each reconstruction should be. The observers were shown the photographs of the 20 individuals (two of the actual individuals and 18 of the volunteers), and asked to identify the most likely match out of the series of photographs to each of the eight reconstructions. Similar identification sessions, where a target individual had to be identified from a face pool (range of photographed faces), were held in studies by Snow *et al.* (1970), Stephan and Henneberg (2001) and Stephan and Cicolini (2008) wherein these procedures were called *face array* tests.

The data were recorded on a scoring sheet that was given to each observer, where he/she had to write down the number of the photograph next to the number of the reconstruction he/she thought it to be associated with (Appendix D). The observers had the option of pointing out a photograph they saw as the best match to each reconstruction, as well as pointing out one or two other possible good matches should they feel that there were more than one likely match. In addition, they were informed that a particular photograph could match more than one reconstruction. They also had the option of stating that no possible match could be made. The accuracy rates were then determined overall by grouping the observers' choices under two classes: *true positive identification* when the photograph was correctly identified as its associate or respective reconstruction, and *false positive identification* when a photograph was identified as a face other than its associated reconstruction. From this, it could be assessed which reconstructions had the highest possibility of being positively identified, and therefore which set of STT's produced the best results.

The second identification session involved another group of 30 individual observers, with and without background in medical science. This group was given the actual photograph of the deceased individual and the set of four reconstructions made on the skull of that individual. The observers were asked to determine the reconstruction he/she felt most resembled the face of the actual individual. The data were recorded on a scoring sheet that was given to each observer, where he/she had to write down the number of the reconstruction he/she thought best matched the photograph next to the number of that photograph (Appendix D). This was done for both individuals A and B. From this it was determined which one of the four sets of STT produced the best results, and if these were significantly different enough to warrant the use of population-specific STT values.

3.2.4 Comparison to other studies

Similar studies to the current study were conducted as early as the late 19th century, where Welcker and His compared their reconstructions to portraits to test their accuracy. More recent studies have also tested this accuracy and its influence in a similar way. The accuracy of facial reconstruction techniques has previously been tested by comparing a reconstruction to the target individual to determine the similarity of the two, a method called *resemblance rating* (Krogman and İşcan 1986; Stephan and Henneberg 2001; Stephan 2002; Stephan and Cicolini 2008). The accuracy has also been tested by determining whether a target individual could be identified from a range of faces (a *face* *pool*) from a facial reconstruction and calculating identification rates for each face (Snow *et al.* 1970; Stephan 2002; Claes *et al.* 2006), a procedure that has also been called *face array* tests (Stephan and Cicolini 2008). Stephan and Henneberg (2001) and Stephan (2002) stated that since a successful FFR depends on the reconstruction being recognisable as the target individual, face fool comparison appears to be more reliable than resemblance ratings as a method of assessing accuracy.

Snow *et al.* (1970) produced two reconstructions (one male and one female) using the American technique, and then used a series of photographs at each reconstruction, including that of the actual deceased individual and six other randomly selected individuals of the same age, sex and race, and asked assessors to select the subject's individual photograph from the series.

Stephan and Henneberg (2001) determined that any of 16 facial reconstructions are sufficiently accurate to produce correct identifications of target individuals above chance. They used casts of four skulls and applied four commonly used methods of facial reconstruction; 3D sculpting American method, a 2D drawing American method, a 2D computer "FACE" assisted American method, and a 3D sculpting combination method. Assessors were asked to attempt to identify a target individual of each facial reconstruction from a face pool of ten photographed faces.

Starbuck and Ward (2007) applied the American method of facial reconstruction and published tissue thickness measurements to test the affect of tissue depth variation on facial reconstructions. They created different reconstructions from different sets of tissue thickness measurements on reproductions of the same skull, and then measured morphological variation with anthropometric craniofacial variability indices. They also held surveys that assessed the subjective appearance of similarity among the faces (Starbuck and Ward 2007). Their research illustrates the baffling effect that normal human variation has in the successful recognition of individuals from 3D facial reconstructions (Starbuck and Ward 2007).

Stephan and Cicolini (2008) used resemblance rating and face array methods to investigate the different assessment methods and its influence on the accuracy of facial reconstructions. For the face array tests, assessors were asked to identify the target face that matched a reconstruction form an array of ten photographs, including the photograph of a deceased individual whose skull was reconstructed. For the resemblance rating test, assessors were asked to score the resemblance between the facial reconstruction and a photograph of the individual, using a rating scale.

As more and more STT data are being developed, more studies like these can be conducted to utilise multiple reconstructions and test the effect that the range of human variation has on the recognition of reconstructions and identification of individuals in forensic investigations, so that these factors can be improved towards higher success rates.

CHAPTER 4: RESULTS

4.1 INTRODUCTION

In this study, both metric and morphological analyses were attempted. The metric data consisted of measurements which were obtained from computerised tomography (CT) scans, then used to develop soft tissue thickness (STT) standards for use on forensic facial reconstruction (FFR). The raw data can be seen in Appendix B. The morphological analysis consisted of facial reconstructions, built up from different data sets, including the newly developed values, to evaluate the usability of these measurements when applied to FFR.

4.2 METRIC ANALYSIS

The metric analysis consisted of measurements, taken from predetermined landmarks on CT scans to the nearest 0.1 millimetre, as described in Chapter 3 (3.1.2 Materials and methods and 3.1.3 Metric analysis). A total of 154 patients' CT scans were used for this purpose. Basic descriptive statistics for the measurements are summarised in Table 4.1.

Every measurement in this study could not be taken from all the CT scans due to a lack of control on the position of the CT scan on the patients, resulting in some of the scans only including the upper half of the face. On some scans there were also other objects such as respiratory tubes or bandages that influenced the clear visibility of the landmarks and skin surface. Therefore, every measurement has a different individual sample size (n), with much smaller sample sizes for measurements on the mandible and lower maxillary region. The smallest sample size at any particular landmark was for G – Mental tubercle (n = 17).

The landmarks that showed the smallest values include A – Supra-glabella (4.7mm), N – Frontal eminence (4.7mm) and O – Fronto-temporale (4.6mm), which all fall on areas on the forehead, and D – End of nasals (2.7mm) and E – Lateral nasal (4.3mm), which fall on the nose. The largest values were measured on the landmarks R – Zygomaxillare (18.7mm), U – Area of the parotid (19.5mm), V – Mid-masseteric (22.4mm), W – Gonion (17.9mm), X – Supra M^2 (30.1mm), Y – Sub M_2 (21.7mm) and Z – Occlusal line (21.6mm). These are all landmarks that fall on the maxilla or mandible, therefore the areas around the mouth and cheeks.

The minimum and maximum is given for each measurement to give an idea of the variation in the subjects who have been measured in this study. It was not the purpose of this study to determine the influence of body build on measurements, or to group the measurements under classes such as thin, medium build or obese, therefore neither thin nor obese patients were excluded from this study. The range was calculated as the difference between the minimum and maximum for each data set. The standard deviation is also a value that indicates variability of the measurements to the mean, that is, how far the data points lie from the mean. The landmarks that show the widest range and standard deviations (indicated in brackets respectively) are R – Zygomaxillare (18.9; 3.427), U – Area of the parotid (19.8; 3.689) , V – Mid-masseteric (22.8; 3.708), W – Gonion (16.3; 4.353) , X – Supra M^2 (17.7; 4.431), Y – Sub M_2 (15.3; 4.254) and Z – Occlusal line (17.1; 3.930). These landmarks fall on the areas around the cheeks, mouth and chin, and are the areas known to be the most variable in STT (De Greef *et al.* 2006) and first to change along with change in body weight and gain or loss of facial fat. This reflects the influence that different body builds can have on the results of the measurements.

The landmarks that show the smallest ranges and standard deviations (indicated in brackets respectively) include A – Supra-glabella (6.1; 1.185), N – Frontal eminence (6.0; 1.256), O – Fronto-temporale (6.8; 1.348) P – Supra-orbital (5.9; 1.371), which fall on areas on the forehead, and D – End of nasals (6.8; 0.975) and E – Lateral nasal (6.2; 1.132), which fall on the nose, and M – Beneath chin (6.0; 1.455) which fall on the mandible.

Table 4.1 Basic descriptive statistics for the measurements of 153 black females between the ages of 18 and 35 years (average age: 27.6 years), (n = sample size for each measurement; SD = standard deviation; min = minimum; max = maximum)

Measurement	n	Mean (in mm)	SD	Mode (in mm)	Min	Max
A – Supra-glabella	150	4.7	1.185	4.1	2.0	8.1
B – Glabella	152	6.3	1.287	5.1	3.1	10.5
C – Nasion	141	6.0	1.552	7.1	2.2	12.0
D – End of nasals	132	2.7	0.975	2.2	1.4	8.2
E – Lateral nasal	148	4.3	1.132	3.9	2.0	8.2
F – Lateral supra-labiale	59	10.2	1.672	-	7.2	14.5
G – Mental tubercle	17	12.6	2.713	-	7.1	17.4
H – Mid-philtrum	138	10.9	1.409	10.8	7.2	14.8
I – Mid upper lip margin	121	13.3	1.761	14.3	7.6	17.7
II – Upper incisor	118	10.3	1.958	10.0	5.1	18.0
J – Mid lower lip margin	95	14.7	1.912	16.1	9.4	21.5
JJ – Lower incisor	99	13.4	1.673	13.9	9.2	21.5
K – Supra-mentale	91	12.2	1.988	10.8	9.1	16.8
L – Mental eminence	64	10.6	1.910	10.0	6.1	17.1
M – Beneath chin	42	6.7	1.455	6.1	4.0	10.0
N – Frontal eminence	148	4.8	1.256	4.3	2.3	8.3
O – Fronto-temporale	148	4.6	1.348	4.6	2.3	9.1
P – Supra-orbital	148	6.8	1.371	6.5	4.0	9.9
Q – Sub-orbital	140	6.9	2.374	-	3.1	13.7
R – Zygomaxillare	83	18.7	3.427	-	7.1	26.0
S – Lateral zygomatic arch	151	8.4	2.767	9.0	3.4	19.9
T – Supra-glenoid	151	12.0	2.188	11.3	7.6	19.2
U – Area of the parotid	145	19.5	3.689	-	9.3	29.1
V – Mid-masseteric	128	22.4	3.708	-	12.1	34.9
W – Gonion	26	17.9	4.353	15.6	11.1	27.4
X – Supra M^2	72	30.1	4.431	29.3	20.1	37.8
Y – Sub M_2	25	21.7	4.254	-	13.4	28.7
Z – Occlusal line	44	21.6	3.930	22.2	14.3	31.4

The measurements were also compared to that of other population groups to assess if statistical differences between the different databases exist. The comparative statistics can be seen in Table 4.2.

When comparing the STT values with results from other studies (Table 4.2), it should be remembered that not all the measurements that were taken in this study were included in studies by other researchers. Also, Rhine and Campbell have not published the standard deviations in their paper, since they were concerned only with extracting data on means and ranges (Rhine and Campbell 1980), thus the variability of the measurements were not available (De Greef *et al.* 2006) and not all the statistical comparisons could be performed. The values from Rhine and Campbell in this study is that quoted from Taylor (2001), but will still be referred to as the Rhine and Campbell (1980) values.

The 95% confidence interval (95% CI) indicates that the value belongs to the distribution with 95% probability (Allan 1982). The end points of the confidence interval (the confidence limits) are indicated in the 95 % CI column.

The difference between the means is the difference in the values between the published results and the current study at each landmark. The landmarks that show the greatest difference between the means of the measurements in various population groups are those around the mouth (X – Supra M^2 and Y – Sub M_2) and angle of the mandible (W – Gonion). It is expected that the greatest difference in appearance of reconstructions will be around these areas, but the influence of this will only be assessed when put to the practical test.

A detailed description of the measurements at each landmark, and a comparison with other databases are given under the relevant headings. Frequencies for the occurrence of specific of STT values at every landmark are indicated in Figures 4.1 to 4.28. In order to better represent the distribution of each measurement in these graphs, all values were rounded off to the nearest 0.5 millimetre. In these figures, the vertical green line indicates the mean and the vertical brown line indicates the mode of the measurement. A mean and mode with a value closer to each other indicates a better normal distribution of the data. The dark grey vertical lines (if indicated on the graph) show two standard deviations (2SD) from the mean of the measurement, which includes 95% of the population. If the dark grey lines are not shown on the graph, the distance for 2SD from the mean falls on an area on the axes not represented by the graph.

At landmarks where skewed data are seen, that is, the mean does not represent the central tendency of the data well, medians and modes may be better descriptions of the data (Domaracki and Stephan 2006). In Table 4.1**,** the mode is included to indicate the most common value. It is compared to the mean in order to assess whether the mean is a good representation of the most frequently occurring value in the population as a whole. The mode will give the most exact and correct estimation for the largest proportion of the sample possible (the most frequent category), but with an error for everyone else (Domaracki and Stephan 2006). It also eliminates the effect of tissue thicknesses of very thin or obese people. The measurements with the greatest difference between the mean and mode (the difference indicated in brackets) are R (Zygomaxillare; 2.26), W (Gonion; 2.07) and Y (SubM_2; 3.07). No value is indicated for the mode at G (Mental tubercle), since no value has been repeated that could be counted as a mode.

The p-value gives an indication as to whether there is a statistical significant difference between the measurements and the level of this significance. The p-value column indicates the significance of the statistical difference of the value from each study versus the current study. Significant difference at $p \leq 0.05$ is indicated in grey, and where $p \leq 0.01$ it is indicated in green.

Table 4.2a Comparison of data from the current study (Current) with that of Manhein *et al.* (2000) (Man), Philips & Smuts (1996) (P&S) and Rhine & Campbell (1980) (R&C)

Landmark	Study	Sample size (n)	Mean (SD)	95% CI	Difference between means	p-value * (vs. current)
A Supra-glabella	Current	150	4.68 (1.19)	(4.488 ; 4.872)	-	-
	Man	-	-	-	-	-
	P&S	16	4.88 (1.02)	(4.336 ; 5.424)	0.20	0.472
	R&C	15	4.50 (-)	-	0.18	0.069
B Glabella	Current	152	6.28 (1.29)	(6.073 ; 6.487)	-	-
	Man	18	4.60 (0.70)	(4.252 ; 4.948)	1.68	0.000
	P&S	16	5.64 (1.42)	(4.883 ; 6.397)	0.64	0.101
	R&C	15	6.00 (-)	-	0.28	0.008
C Nasion	Current	141	6.00 (1.55)	(5.740 ; 6.260)	-	-
	Man	18	6.00 (0.84)	(5.582 ; 6.418)	0.00	1.000
	P&S	16	4.68 (2.35)	(3.428 ; 5.932)	1.32	0.043
	R&C	15	5.25 (-)	-	0.75	0.000
D End of nasals	Current	132	2.72 (0.98)	(2.542 ; 2.882)	-	-
	Man	18	1.70 (0.46)	(1.471 ; 1.929)	1.01	0.000
	P&S	16	2.78 (0.91)	(2.295 ; 3.265)	0.07	0.783
	R&C	15	3.75 (-)	-	1.04	0.000
E Lateral nasal	Current	148	4.26 (1.13)	-	-	-
	Man	-	-	-	-	-
	P&S	-	-	-	-	-
	R&C	-	-	-	-	-
F Lateral supra-labiale	Current	59	10.19 (1.67)	(9.755 ; 10.625)	-	-
	Man	18	10.00 (2.28)	(8.866 ; 11.134)	0.19	0.746
	P&S	-	-	-	-	-
	R&C	-	-	-	-	-
G Mental tubercle	Current	17	12.61 (2.71)	(11.227 ; 13.993)	-	-
	Man	18	12.60 (2.85)	(11.183 ; 14.017)	0.01	0.992
	P&S	-	-	-	-	-
	R&C	-	-	-	-	-
H Mid-philtrum	Current	138	10.92 (1.41)	(10.683 ; 11.157)	-	-
	Man	18	9.20 (1.82)	(8.295 ; 10.105)	1.72	0.001
	P&S	16	10.13 (2.48)	(8.809 ; 11.452)	0.79	0.229
	R&C	15	11.25 (-)	-	0.33	0.006
I Mid upper lip margin	Current	121	13.30 (1.76)	(12.983 ; 13.617)	-	-
	Man	-	-	-	-	-
	P&S	-	-	-	-	-
	R&C	15	12.50 (-)	-	0.8	0.000

* $p \leq 0.05$ indicated in grey; $p \leq 0.01$ indicated in green.

Table 4.2b Comparison of data from the current study (Current) with that of Manhein *et al.* (2000) (Man), Philips & Smuts (1996) (P&S) and Rhine & Campbell (1980) (R&C)

Landmark	Study	Sample size (n)	Mean (SD)	95% CI	Difference between means	p-value * (vs. current)
II Upper incisor	Current	118	10.32 (1.96)	(9.963 ; 10.677)	-	-
	Man	-	-	-	-	-
	P&S	16	13.63 (3.7)	(11.658 ; 15.602)	3.31	0.003
	R&C	-	-	-	-	-
J Mid lower lip margin	Current	95	14.65 (1.91)	(14.264 ; 15.043)	-	-
	Man	-	-	-	-	-
	P&S	-	-	-	-	-
	R&C	15	15.00 (-)	-	0.35	0.081
JJ Lower incisor	Current	99	13.39 (1.67)	(13.059 ; 13.721)	-	-
	Man	-	-	-	-	-
	P&S	16	12.45 (2.31)	(11.219 ; 13.681)	0.94	0.135
	R&C	-	-	-	-	-
K Supra-mentale	Current	91	12.21 (1.99)	(11.796 ; 12.624)	-	-
	Man	18	11.80 (2.20)	(10.706 ; 12.894)	0.41	0.471
	P&S	16	11.70 (1.66)	(10.815 ; 12.585)	0.51	0.283
	R&C	15	12.25 (-)	-	0.04	0.831
L Mental eminence	Current	64	10.61 (1.91)	(10.133;11.087)	-	-
	Man	18	10.80 (2.68)	(9.467 ; 12.133)	0.19	0.781
	P&S	16	9.57 (2.36)	(8.312 ; 10.828)	1.04	0.117
	R&C	15	12.50 (-)	-	1.89	0.000
M Beneath chin	Current	42	6.72 (1.46)	(6.265 ; 7.175)	-	-
	Man	18	6.70 (2.02)	(5.695 ; 7.705)	0.02	0.970
	P&S	16	6.47 (1.57)	(5.633 ; 7.307)	0.25	0.585
	R&C	15	8.00 (-)	-	1.28	0.000
N Frontal eminence	Current	148	4.75 (1.26)	(4.545 ; 4.955)	-	-
	Man	-	-	-	-	-
	P&S	16	4.78 (1.74)	(3.853 ; 5.707)	0.03	0.947
	R&C	15	4.00 (-)	-	0.75	0.000
O Fronto-temporale	Current	148	4.60 (1.35)	-	-	-
	Man	-	-	-	-	-
	P&S	-	-	-	-	-
	R&C	-	-	-	-	-
P Supra-orbital	Current	148	6.84 (1.37)	(6.617 ; 7.063)	-	-
	Man	18	6.10 (0.83)	(5.687 ; 6.513)	0.74	0.003
	P&S	16	5.79 (1.89)	(4.783 ; 6.797)	1.05	0.045
	R&C	15	8.00 (-)	-	1.16	0.000

* $p \leq 0.05$ indicated in grey; $p \leq 0.01$ indicated in green.

Table 4.2c Comparison of data from the current study (Current) with that of Manhein *et al.* (2000) (Man), Philips & Smuts (1996) (P&S) and Rhine & Campbell (1980) (R&C)

Landmark	Study	Sample size (n)	Mean (SD)	95% CI	Difference between means	p-value * (vs. current)
Q Sub-orbital	Current	140	6.89 (2.37)	(6.494 ; 7.286)	-	-
	Man	18	6.20 (1.17)	(5.618 ; 6.782)	0.69	0.050
	P&S	16	6.42 (3.83)	(4.379 ; 8.461)	0.47	0.637
	R&C	15	8.25 (-)	-	1.36	0.000
R Zygomaxillare	Current	83	18.67 (3.43)	(17.920;19.417)	-	-
	Man	-	-	-	-	-
	P&S	-	-	-	-	-
	R&C	15	16.75 (-)	-	1.92	0.000
S Lateral zygomatic arch	Current	151	8.41 (2.77)	(7.965 ; 8.855)	-	-
	Man	18	6.40 (2.25)	(5.281 ; 7.519)	2.01	0.002
	P&S	16	9.30 (3.21)	(7.590 ; 11.01)	0.89	0.299
	R&C	15	9.50 (-)	-	1.09	0.000
T Supra-glenoid	Current	151	12.01 (2.19)	(11.658;12.362)	-	-
	Man	18	6.40 (2.25)	(5.281 ; 7.519)	5.61	0.000
	P&S	16	8.44 (3.84)	(6.394 ; 10.486)	3.57	0.002
	R&C	15	11.50 (-)	-	0.51	0.005
U Area of the parotid	Current	145	19.51 (3.69)	-	-	-
	Man	-	-	-	-	-
	P&S	-	-	-	-	-
	R&C	-	-	-	-	-
V Mid-masseteric	Current	128	22.38 (3.71)	-	-	-
	Man	-	-	-	-	-
	P&S	-	-	-	-	-
	R&C	-	-	-	-	-
W Gonion	Current	26	17.90 (4.35)	(16.143;19.657)	-	-
	Man	18	18.00 (4.23)	(16.291;19.709)	0.10	0.941
	P&S	16	13.50 (6.60)	(9.983 ; 17.017)	4.40	0.026
	R&C	15	13.50 (-)	-	4.40	0.000
X Supra M^2	Current	72	30.11 (4.43)	(29.069;31.151)	-	-
	Man	18	26.60 (4.36)	(24.432;28.768)	3.51	0.005
	P&S	16	12.99 (4.45)	(10.619;15.361)	17.12	0.000
	R&C	15	20.25 (-)	-	9.86	0.000
Y Sub M_2	Current	25	21.67 (4.25)	(19.916;23.424)	-	-
	Man	18	21.70 (3.99)	(19.716;23.684)	0.03	0.981
	P&S	16	11.88 (5.95)	(8.709;15.051)	9.79	0.000
	R&C	15	17.00 (-)	-	4.67	0.000
Z Occlusal line	Current	44	21.60 (3.93)	(20.405;22.795)	-	-
	Man	-	-	-	-	-
	P&S	16	21.26 (8.37)	(16.800;25.720)	0.34	0.878
	R&C	15	19.25 (-)	-	2.35	0.0003

* $p \leq 0.05$ indicated in grey; $p \leq 0.01$ indicated in green.

4.2.1 Assessment of values from the current study at the various landmarks

A – Supra-glabella

This is a measurement on the forehead, superior to the glabella. It was measured in 150 individuals. The mean value was 4.68 mm (SD = 1.18, range = 6.1). The range is calculated as the difference between the minimum and maximum at each landmark. The mode is 4.1, a fairly good reflection of the mean. Figure 4.1 shows the frequency distribution of the measurements for A, with most of the measurements concentrated around the mean and mode.

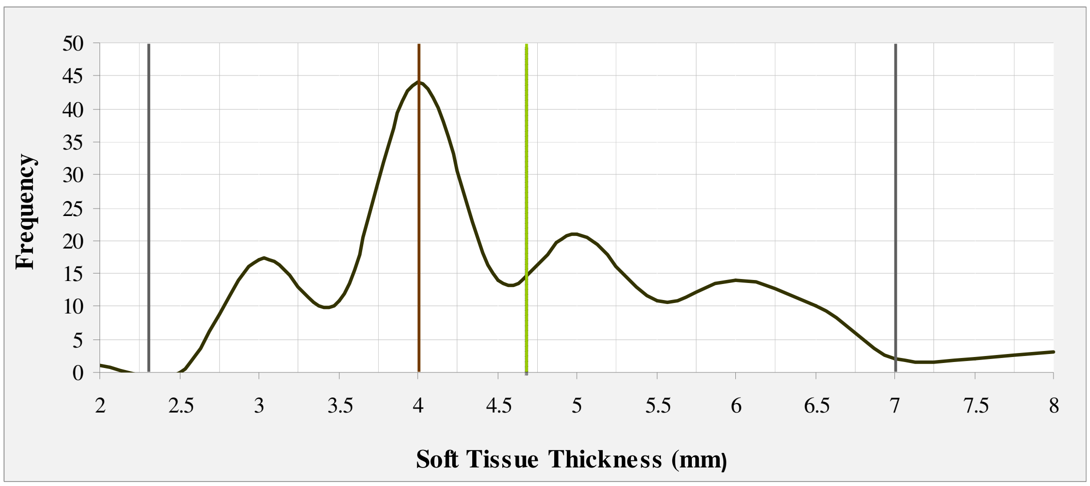

Figure 4.1 Distribution of the measurements of A – Supra-glabella. The vertical green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

The value for the supra-glabella from Phillips and Smuts (1996) is 4.88 mm and Rhine and Campbell (1980) 4.50 mm, which is not significantly different from the current study. This measurement was not included by Manhein *et al.* (2000).

B – Glabella

This is a measurement on the most prominent point on the forehead, between the supra-orbital brow ridges. It was measured in 152 individuals. The mean value was 6.28 mm, (SD = 1.29, range = 7.4, mode = 5.1). Figure 4.2 shows the frequency distribution of the measurements for B, with most of the measurements concentrated around the mean and mode, and with 3 outliers above and 1 below 2SD from the mean.

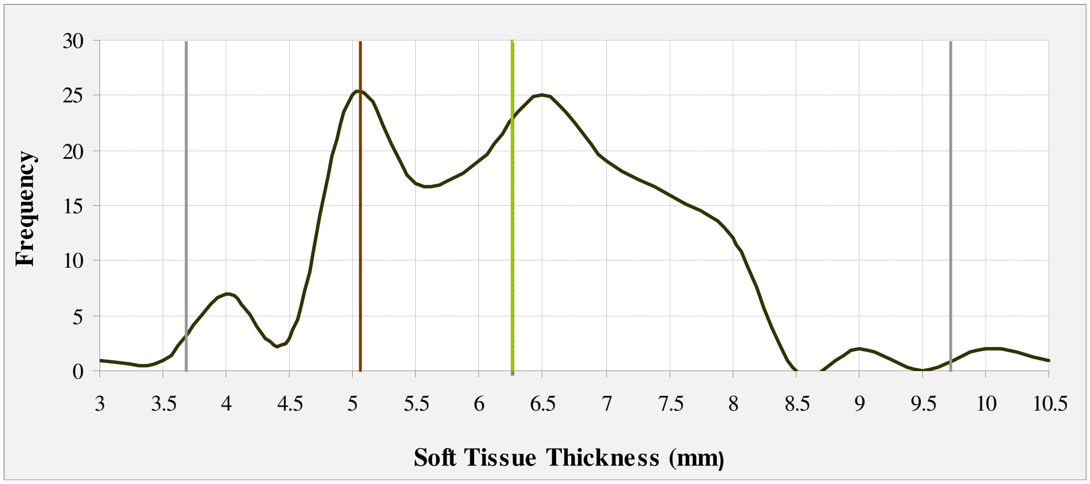

Figure 4.2 Distribution of the measurements of B – Glabella. The vertical green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

The values for the supra-glabella from Manhein *et al.* (2000) of 4.60 mm and Rhine and Campbell (1980) of 6.00 mm are both statistically significantly different from that of the current study. The value from Phillips and Smuts (1996) of 5.64 mm is not significantly different from the current study.

C – Nasion

This is a measurement on the forehead in the midline on the suture between the frontal bone and two nasal bones. It was measured in 141 individuals. The mean value was 6.00 mm (SD = 1.55, range = 9.8, mode = 7.1). Figure 4.3 shows the frequency distribution of the measurements for C. Most of the measurements of the study population are concentrated around the mean and mode of the measurement.

This value is not significantly different from Manhein *et al.*'s (2000) value of 6.00 mm, but is different from that of Phillips and Smuts (1996) of 4.68 mm (p = 0.043), and from Rhine and Campbell (1980) of 5.25 mm (p = 0.000).

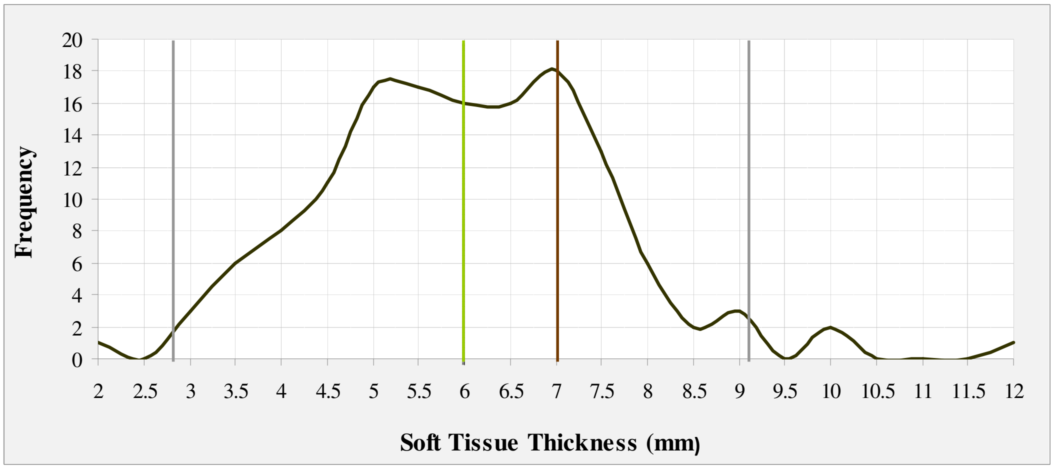

Figure 4.3 Distribution of the measurements of C – Nasion. The vertical green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

D – End of nasals

This is a measurement on the most anterior tip of the bony part of the nasal bones, before the bone-cartilage junction. It was measured in 132 individuals. The mean value was 2.72 mm (SD = 0.98, range = 6.8). The mode is 2.2, a fairly good representation of the mean. Figure 4.4 shows the frequency distribution of the measurements for D. Although most of the measurements are concentrated around the mean, the distribution is skewed to the left due to seven outliers with much larger values and lying far above the upper limit of 2SD.

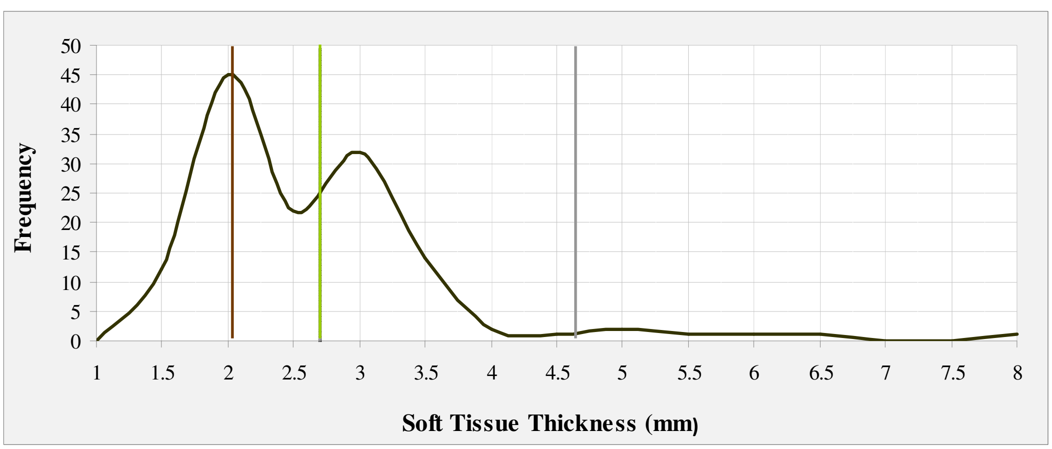

Figure 4.4 Distribution of the measurements of D – End of nasals. The vertical green line indicates the mean, brown line the mode, and grey line the upper limit of 2SD

This value has no significant difference from that of Phillips and Smuts (1996) of 2.78 mm, but is statistically different from that of Manhein *et al.* (2000) 1.70 mm (p = 0.000) and Rhine and Campbell (1980) of 3.75 mm (p = 0.000). Since some of the databases' values are higher, and others lower, it indicates that the measurement shows either a high degree of variability or that it is difficult to measure accurately.

E – Lateral nasal

This is a measurement on the side of the bridge of the nose at the level of the inner corner of the eye. It was measured in 148 individuals. The mean value was 4.26 mm (SD = 1.13, range = 6.2). The mode was 3.9, a good representation of the mean. Figure 4.5 shows the frequency distribution of the measurements for E, which is a fairly normal distribution, with most of the measurements concentrated around the mean and mode, although five outliers are seen above 2SD (upper limit).

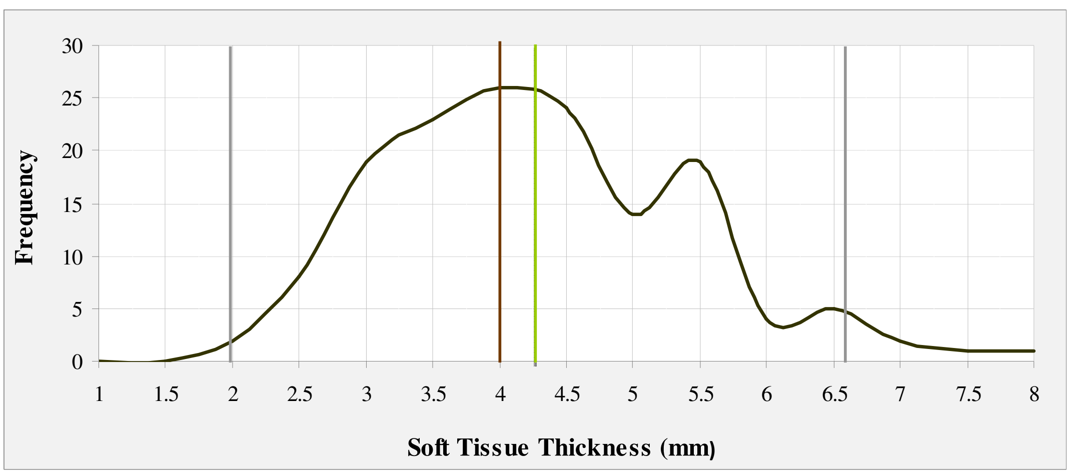

Figure 4.5 Distribution of the measurements of E – Lateral nasal. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

The lateral nasal measurement was not included in any of the studies by Manhein *et al.* (2000), Phillips and Smuts (1996) or Rhine and Campbell (1980).

F – Lateral supra-labiale

This is a measurement on the maxilla, on the maximum bulge of the maxillary canine. It was measured in 59 individuals. The mean value was 10.2 mm (SD = 1.67, the range 7.3). No value is indicated as the mode, as there were several values that occurred as the most frequent value in the data series. Figure 4.6 shows the frequency distribution of the measurements for F. This frequency distribution does not show a normal distribution, but shows a large general variation in this measurement for the study population and a few outliers are seen above 2SD.

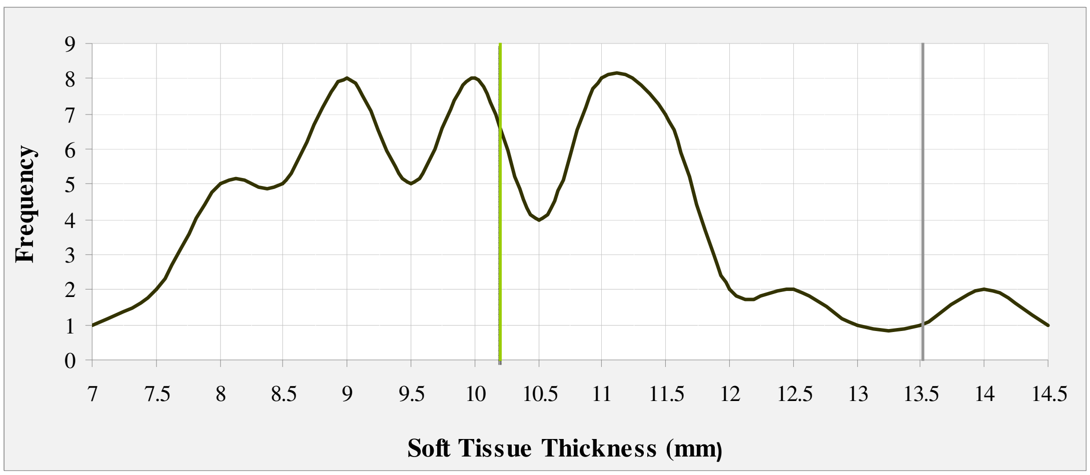

Figure 4.6 Distribution of the measurements of F – Lateral supra-labiale. The green line indicates the mean and grey line the upper limit of 2SD

The lateral supra-labiale measurement was only included in the study by Manhein *et al.* (2000) with a value of 10.00 mm, which is not significantly different from the mean value in the current study.

G – Mental tubercle

This is a measurement on the mandible, on the most prominent point on the bulge just lateral to the chin. It was measured in 17 individuals. The mean value was 12.61 mm (SD = 2.71, range 10.3). No value was calculated as the mode, that is, no value occurred more frequently than any other. Figure 4.7 shows the frequency distribution of the measurements for G. A high degree of variation is seen in this frequency distribution.

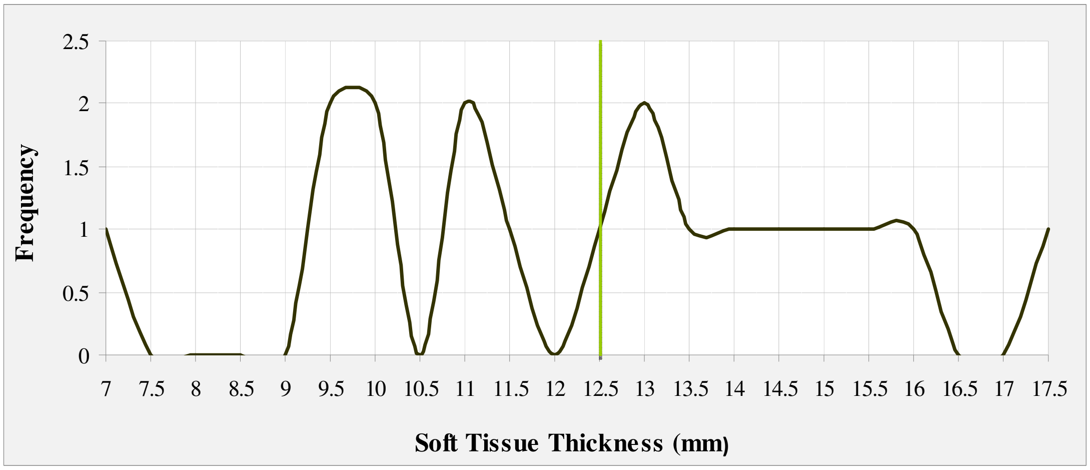

Figure 4.7 Distribution of the measurements of G – Mental tubercle. The vertical green line indicates the mean

This measurement was only included in the study by Manhein *et al.* (2000) with a value of 12.60 mm, which is not significantly different from current study.

H – Mid-philtrum

This is a measurement in the midline on the maxilla, halfway between the nasal spine and central upper incisors. It was measured in 138 individuals. The mean value was 10.92 mm (SD 1.41, range 7.6). The mean and mode (10.8) are very accurate representations of each other. Figure 4.8 shows the frequency distribution of the measurements for H, which follows a fairly normal distribution. Outliers are seen far below the lower limit and above the upper limit of 2SD, but most of the measurements are concentrated around the mean.

This value from Manhein *et al.* (2000) is 9.20 mm and from Rhine and Campbell (1980) 11.25 mm, both statistically significantly different from the mean of the current study. The value from Phillips and Smuts (1996) is 10.13 mm, with no statistical difference from the current study.

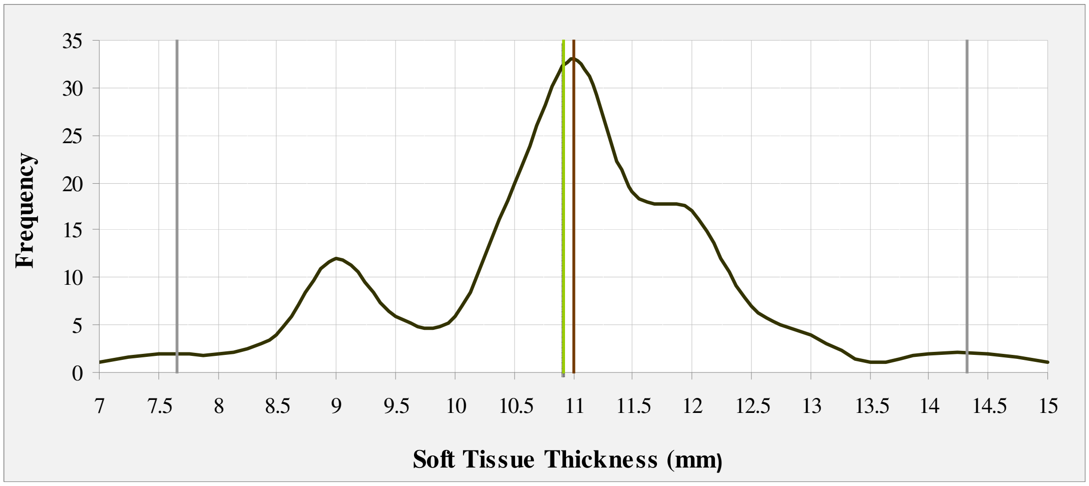

Figure 4.8 Distribution of the measurements of H – Mid-philtrum. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

I – Mid upper lip margin

This is a measurement on the midline of the maxilla, between the alveolar sockets of the upper central incisors. It was measured in 121 individuals. The mean value was 13.30 mm (SD = 1.76, range 10.1, mode = 14.3). Figure 4.9 shows the frequency distribution of the measurements for I. The distribution shows a high degree of variation in the measurements, with outliers below the lower limit and above the upper limit of 2SD, however most of the measurements lie close to the mean or mode.

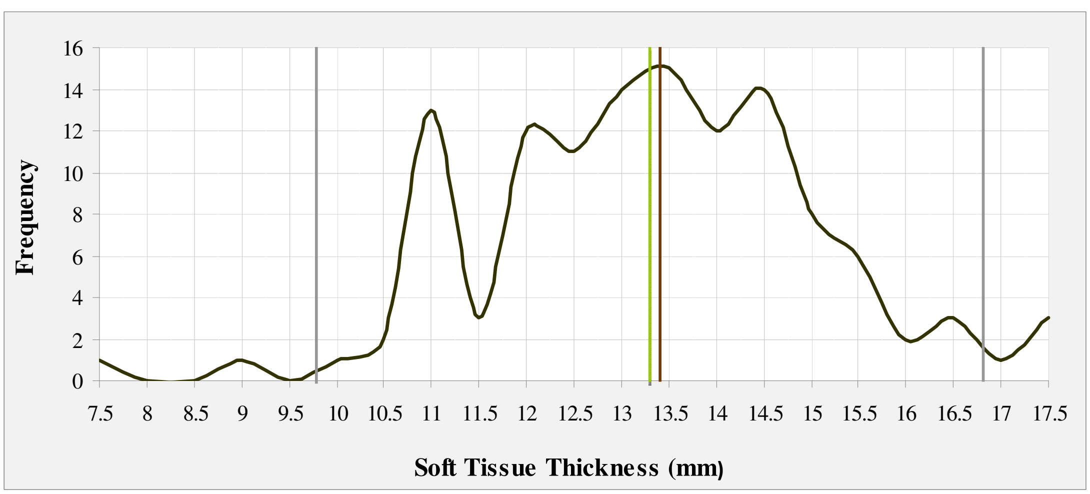

Figure 4.9 Distribution of the measurements of I – Mid upper lip margin. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

This measurement was only included in the study by Rhine and Campbell (1980), with a value of 12.50 mm, which is significantly different from the mean of the current study (p = 0.000).

II – Upper incisor

This measurement was taken on the crown of the upper central incisor. It was measured in 118 individuals. The mean value was 10.32 mm (SD 1.96, the range 12.9, mode = 10.0). The mode and the mean are good representations of each other. Figure 4.10 shows the frequency distribution of the measurements for II, which shows most of the measurements concentrated around the mean, although outliers are seen below the lower limit and far above the upper limit of 2SD.

This measurement was only included in the study by Phillips and Smuts (1996), with a value of 13.62 mm, which is significantly different from the current study (p = 0.003).

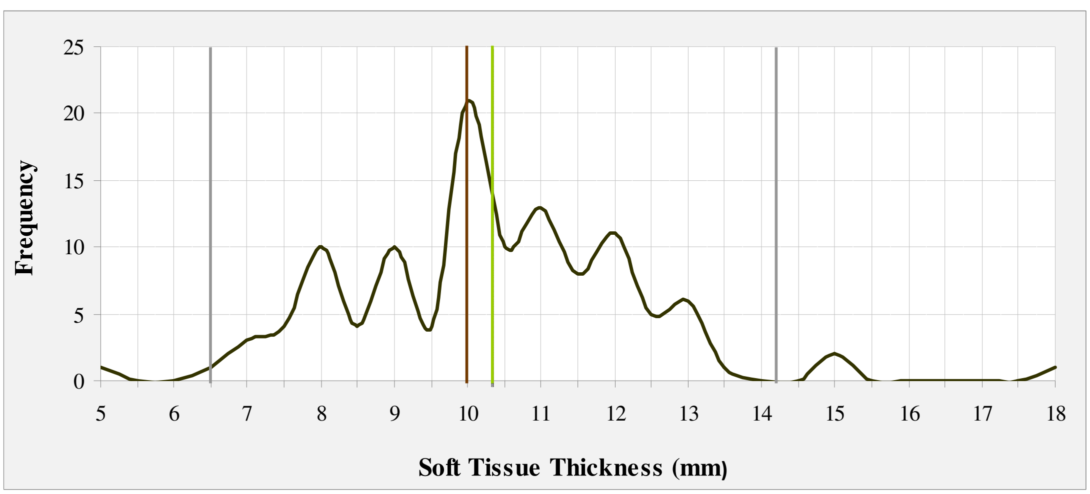

Figure 4.10 Distribution of the measurements of II – Upper incisor. The green line indicates the mean, brown line the mode, and the grey lines the lower and upper limits of 2SD

J – Mid lower lip margin

This is a measurement on the midline of the mandible, between the alveolar sockets of the lower central incisors. It was measured in 95 individuals. The mean value was 14.65

mm (SD = 1.91, range = 12.1, mode = 16.1). Figure 4.11 shows the frequency distribution of the measurements for J, which is a fairly normal distribution, with most of the measurements concentrated around the mean, although outliers are seen below the lower limit and far above the upper limit of 2SD.

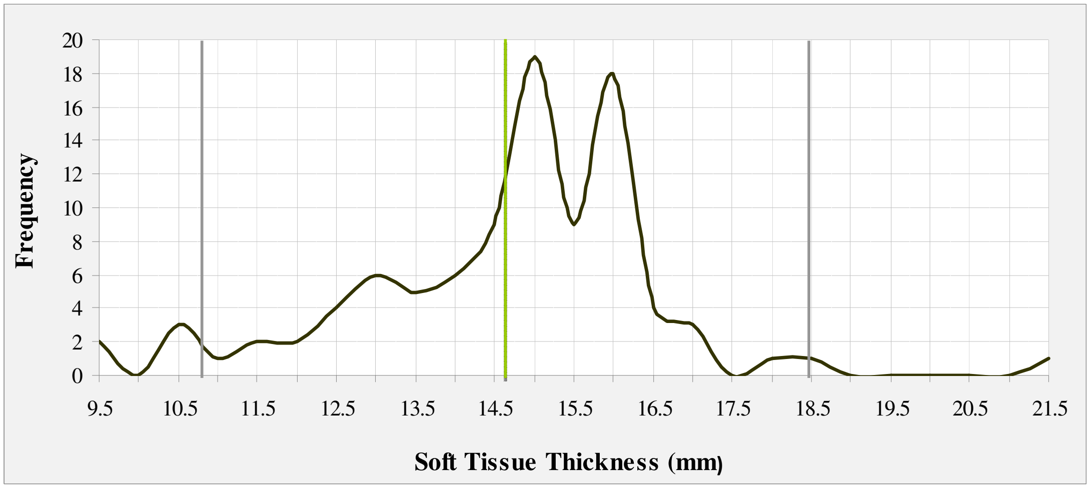

Figure 4.11 Distribution of the measurements of J – Mid lower lip margin. The green line indicates the mean and grey lines the lower and upper limits of 2SD

The mid lower lip margin measurement was only included in the study by Rhine and Campbell (1980), with a mean value of 15.00 mm, which is not significantly different from the mean of the current study.

JJ – Lower incisor

This measurement was taken on the crown of the lower central incisor. It was measured in 99 individuals. The mean value was 13.4 mm (SD = 1.67, range = 12.3). The mode, 13.9, and the mean are good representations of each other. Figure 4.12 shows the frequency distribution of the measurements for JJ. Most of the measurements of the study population are concentrated around the mean, although one individual fell far outside the fairly normally distributed sample.

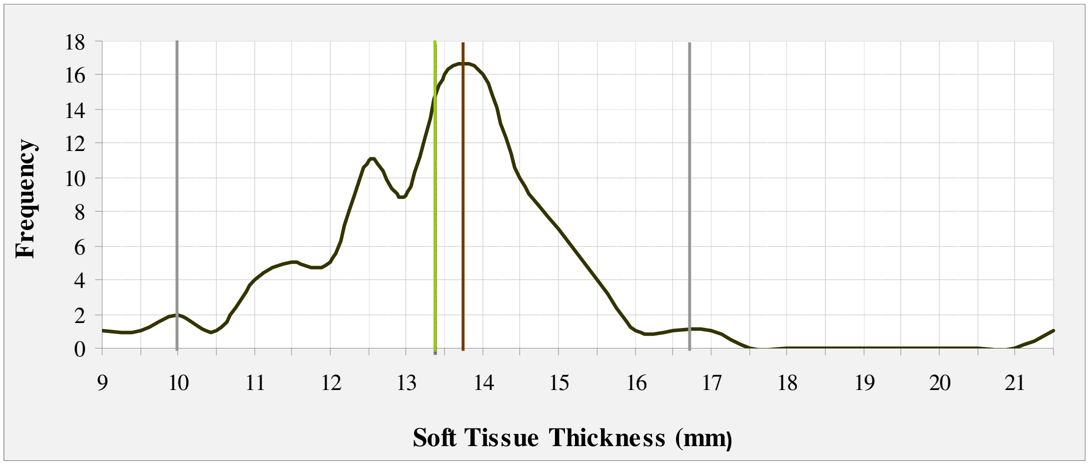

Figure 4.12 Distribution of the measurements of JJ – Lower incisor. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

The lower incisor measurement was only included in the study by Phillips and Smuts (1996), with a value of 12.45 mm, which is not significantly different from the mean of the current study.

K – Supra-mentale

This is a measurement on the midline of the mandible, in the indentation where the chin-lip fold would fall. It was measured in 91 individuals. The mean value was 12.21 mm (SD = 1.99, range = 7.7, mode = 10.8). Figure 4.13 shows the frequency distribution of the measurements for K, which is not a sample showing a normal distribution, but a high degree of variation in the measurements at this landmark.

The value for the supra-mentale from Manhein *et al.* (2000) is 11.80 mm, Phillips and Smuts (1996) 11.80 mm, and Rhine and Campbell (1980) 12.25 mm. None of these were significantly different from the mean value of the study population.

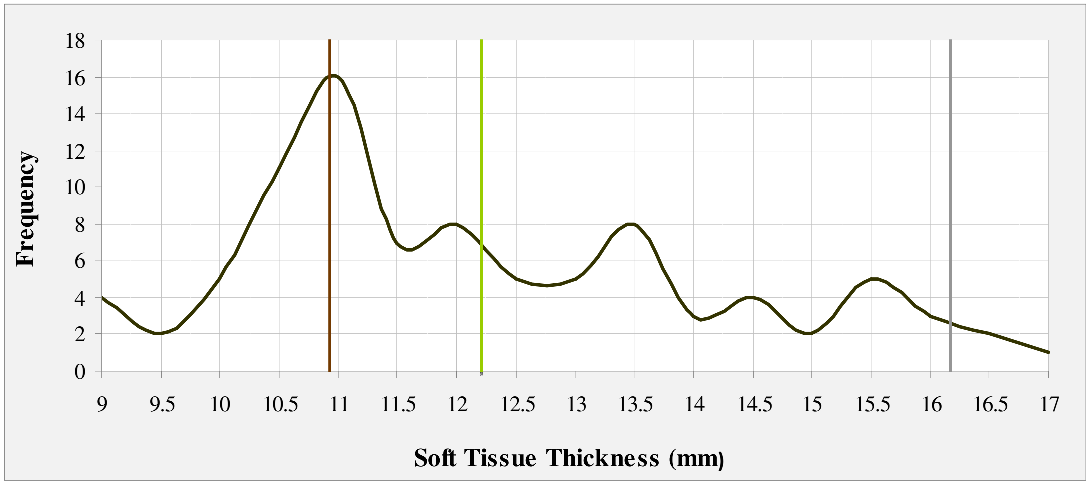

Figure 4.13 Distribution of the measurements of K – Supra-mentale. The green line indicates the mean, brown line the mode, and grey line the upper limit of 2SD

L – Mental eminence

This is a measurement on the midline of the mandible, on the most prominent point of the chin. It was measured in 64 individuals. The mean value was 10.61 mm, (SD = 1.91, range = 11.0, mode = 10.0). The mean and mode are fairly good representations of each other. Figure 4.14 shows the frequency distribution of the measurements for L. Most of the measurements of the study population are concentrated around the mean, indicated by the fairly normal distribution. Three outliers are seen above the upper limit of 2SD.

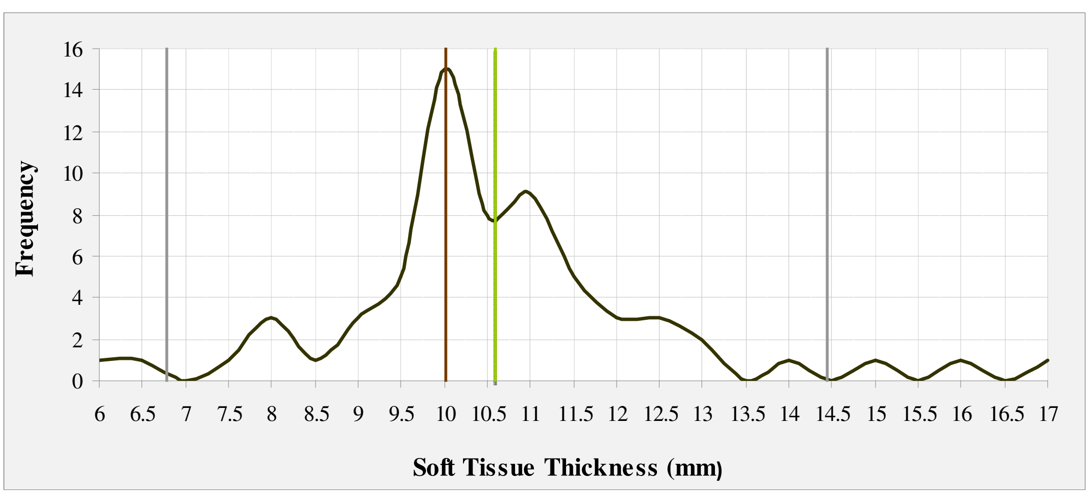

Figure 4.14 Distribution of the measurements of L – Mental eminence. The green line indicates the mean, brown line the mode, and the grey lines the lower and upper limits of 2SD

The value for the mental eminence from Manhein *et al.* (2000) is 10.80 mm, Phillips and Smuts (1996) 9.57 mm, and Rhine and Campbell (1980) 12.50 mm. Of these, only the value from Rhine and Campbell were calculated to be significantly different from the mean of the study population (p = 0.000).

M – Beneath chin

This is a measurement on the lower border of the mandible, projecting inferiorly from the surface of the bone. It was measured in 42 individuals. The mean value was 6.72 mm (SD = 1.46, range = 6.0). The mode, 6.1, is a good representation of the mean. Figure 4.15 shows the frequency distribution of the measurements for M. A high degree of variation is seen, although most of the measurements still fall within the limits of 2SD from the mean.

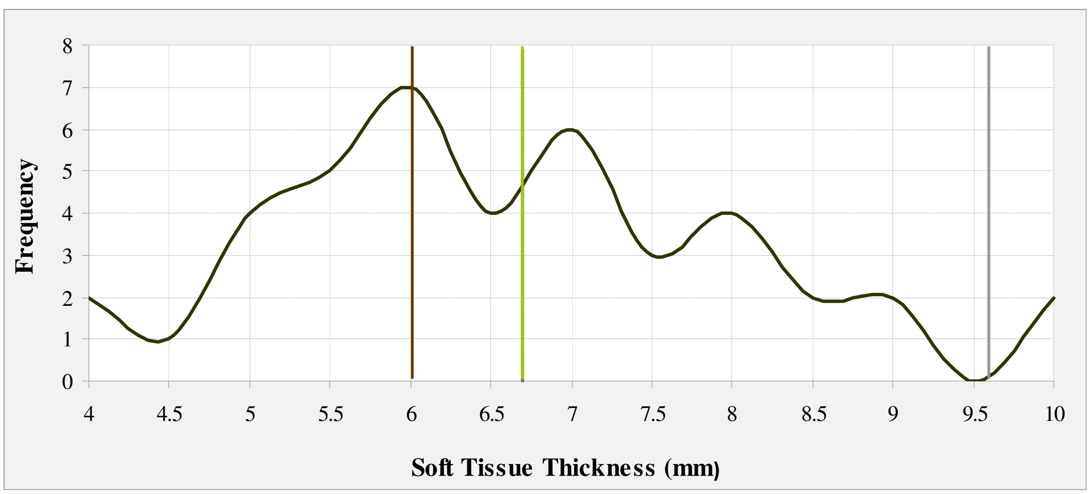

Figure 4.15 Distribution of the measurements of M – Beneath chin. The green line indicates the mean, brown line the mode, and grey line the upper limit of 2SD

This value from Manhein *et al.* (2000) is 6.70 mm, Phillips and Smuts (1996) 6.47 mm, and Rhine and Campbell (1980) 8.00 mm. Of these, only the value from Rhine and Campbell (1980) were significantly different from the mean of the study population (p = 0.000).

N – Frontal eminence

This is a measurement on the frontal bone, superior to the orbit and lateral to the supra-glabella. It was measured in 148 individuals. The mean value was 4.75 mm (SD = 1.26, range = 6.0). The mode, 4.3, is a very good reflection of the mean. Figure 4.16 shows the frequency distribution of the measurements for N. A high degree of variation is seen, with most of the measurements concentrated around the mean, but with outliers also found far above 2SD.

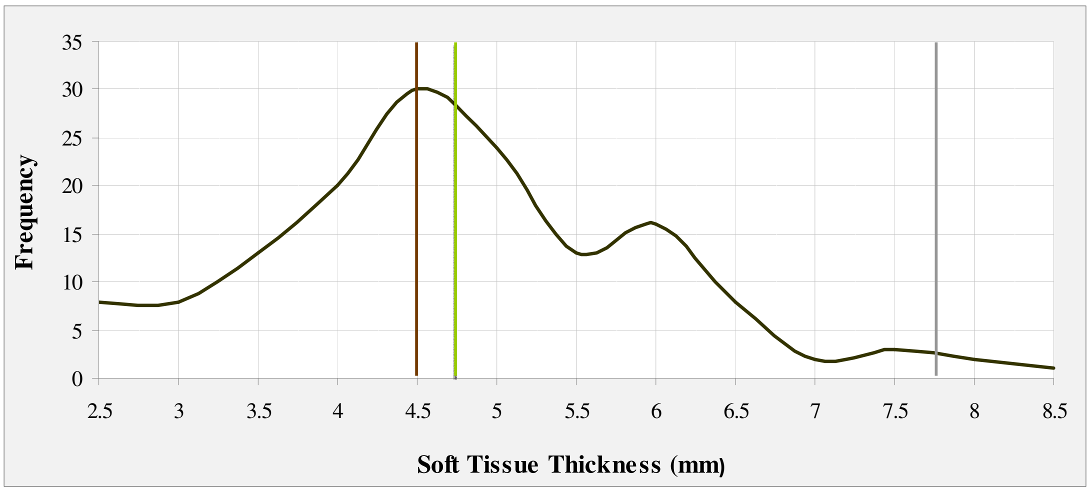

Figure 4.16 Distribution of the measurements of N – Frontal eminence. The green line indicates the mean, brown line the mode, and the grey line the upper limit of 2SD

This value from Phillips and Smuts (1996) is 4.78 mm, which is not significantly different from the mean of the current study. The value from Rhine and Campbell (1980) is 4.00 mm, which were calculated to be significantly different from the mean of the study population. This value was not included in the study by Manhein *et al.* (2000).

O – Fronto-temporale

This is a measurement on the temporal line of the frontal bone. It was measured in 148 individuals. The mean value was 4.60 mm (SD = 1.35, range = 6.8). The mode, 4.60, is an accurate reflection of the mean. Figure 4.17 shows the frequency distribution of the measurements for O. Most of the measurements of the study population are concentrated around the mean, although outliers are seen far above 2SD from the mean. This measurement was not included in any of the other studies.

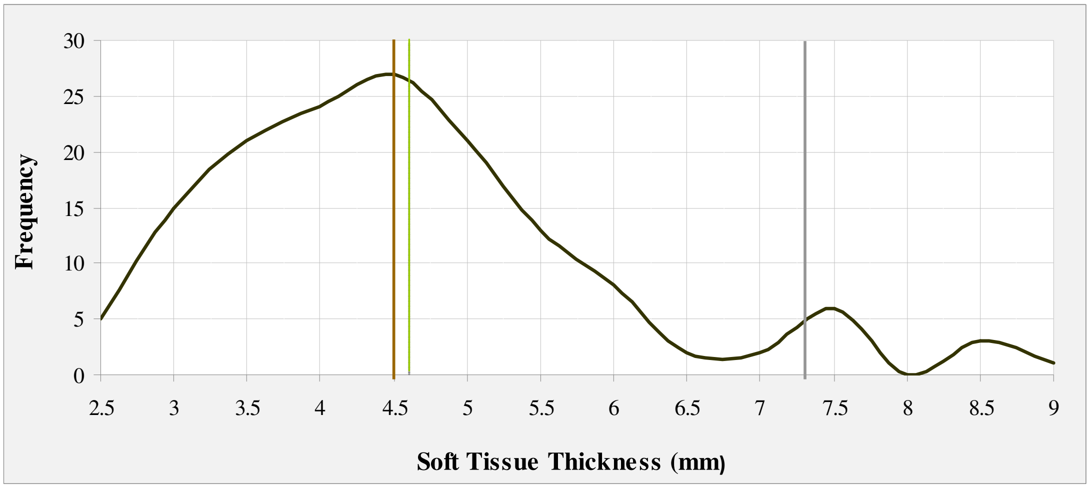

Figure 4.17 Distribution of the measurements of O – Fronto-temporale. The green line indicates the mean, brown line the mode, and grey line the upper limit of 2SD

P – Supra-orbital

This measurement was taken on the most superior point on the upper rim of the orbit. It was measured in 148 individuals. The mean value was 6.84 mm (SD = 1.37, range = 5.9). The mode of 6.5 and the mean are good representations of each other. Figure 4.18 shows the frequency distribution of the measurements for P. Most of the measurements in the study population are concentrated around the mean, although a high degree of variation is seen in the distribution of the data set, but these variations still fall within the limit of 2SD from the mean.

The supra-orbital value from Manhein *et al.* (2000) of 6.10 mm (p = 0.003), Phillips and Smuts (1996) of 5.79 mm (p = 0.045) and Rhine and Campbell (1980) of 8.00 mm (p = 0.000), were all significantly different from the mean value of the study population.

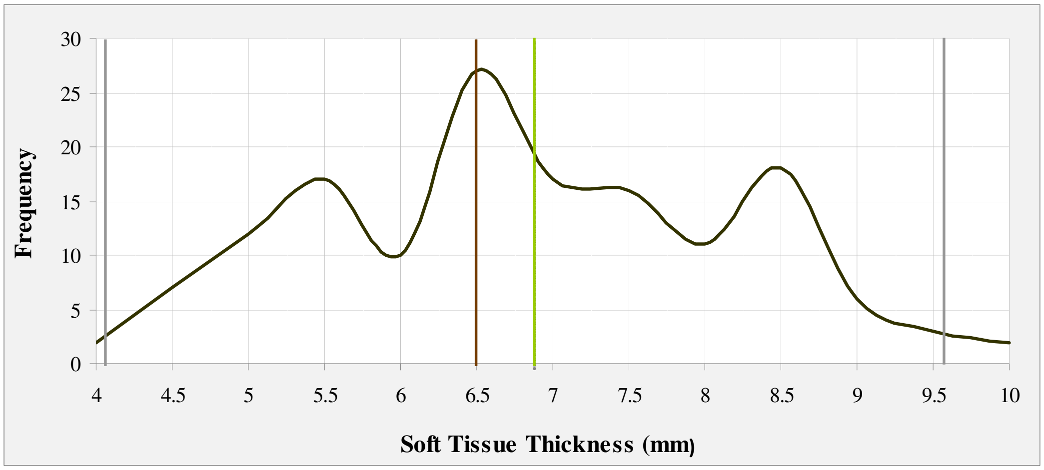

Figure 4.18 Distribution of the measurements of P – Supra-orbital. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

Q – Sub-orbital

This is a measurement on most inferior point on the lower rim of the orbit. It was measured in 140 individuals. The mean value was 6.89 mm (SD = 2.37, range = 10.6). Figure 4.19 shows the frequency distribution of the measurements for Q. No value is indicated as the mode, as there actually were two values in the non-rounded data that occurred as the most frequent value in the data series. Most of the measurements of the study population are concentrated around the mean. The outliers seen above 2SD from the mean caused the distribution to be skewed to the left.

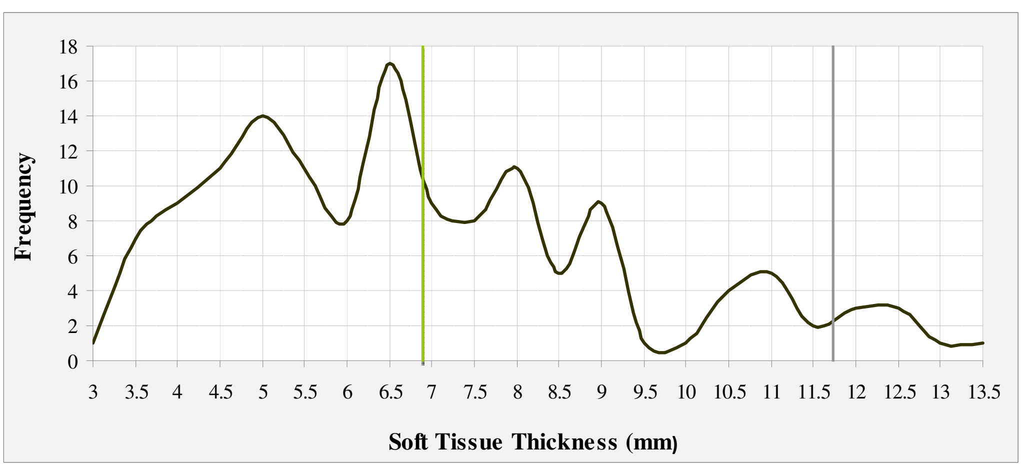

Figure 4.19 Distribution of the measurements of Q – Sub-orbital. The green line indicates the mean and grey line the upper limit of 2SD

The values for the sub-orbital measurement from Manhein *et al.* (2000) of 6.20 mm (p = 0.050) and Rhine and Campbell (1980) of 8.25 mm (p = 0.000) both show a statistically significant difference from that of the current study. The value of Phillips and Smuts (1996) is 6.20 mm, which is not significantly different.

R – Zygomaxillare

This is a measurement on the zygomaxillary suture, inferior to the sub-orbital measurement. It was measured in 83 individuals. The mean value was 18.67 mm (SD = 3.43, range = 19.9). . No value is indicated as the mode, as there actually were two values in the non-rounded data that occurred as the most frequent value in the data series. Figure 4.20 shows the frequency distribution of the measurements for R. Most of the measurements of the study population are concentrated around the mean, although a high degree of variation is seen in the distribution of the data set, and outliers are seen far above the mean and below 2SD from the mean.

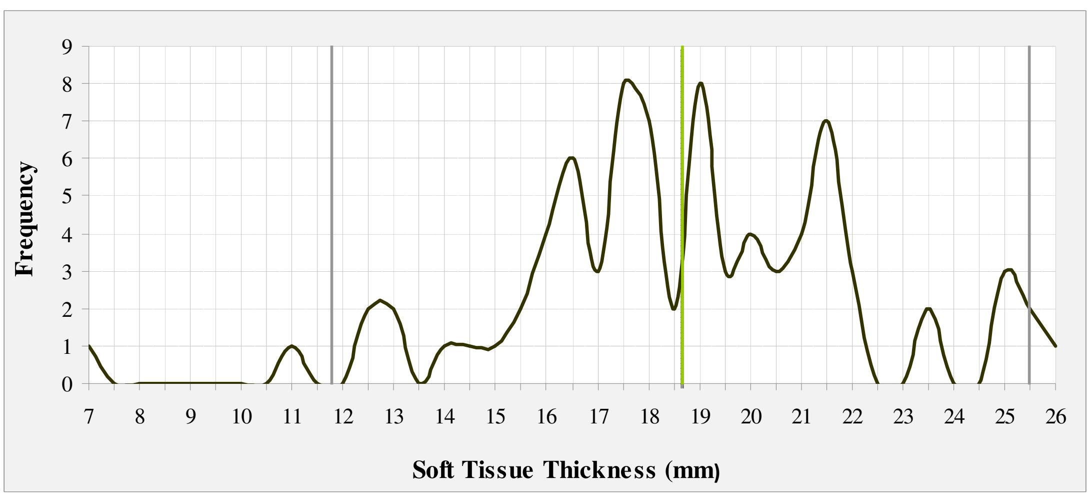

Figure 4. 20 Distribution of the measurements of R – Zygomaxillare. The green line indicates the mean and grey lines the lower and upper limits of 2SD

This measurement was only included by Rhine and Campbell (1980), with a value of 16.75 mm, which is significantly different from the mean of the current study (p = 0.000).

S – Lateral zygomatic arch

This is a measurement on the maximum lateral outer curvature of the zygomatic arch. It was measured in 151 individuals. The mean value was 8.41 mm (SD = 2.77, range = 16.5). The mode, 9.0, is a fairly good representation of the mean. Figure 4.21 shows the frequency distribution of the measurements for S. Most of the measurements of the study population are concentrated around the mean, although outliers are seen far above 2SD from the mean, causing the distribution to be skewed to the left.

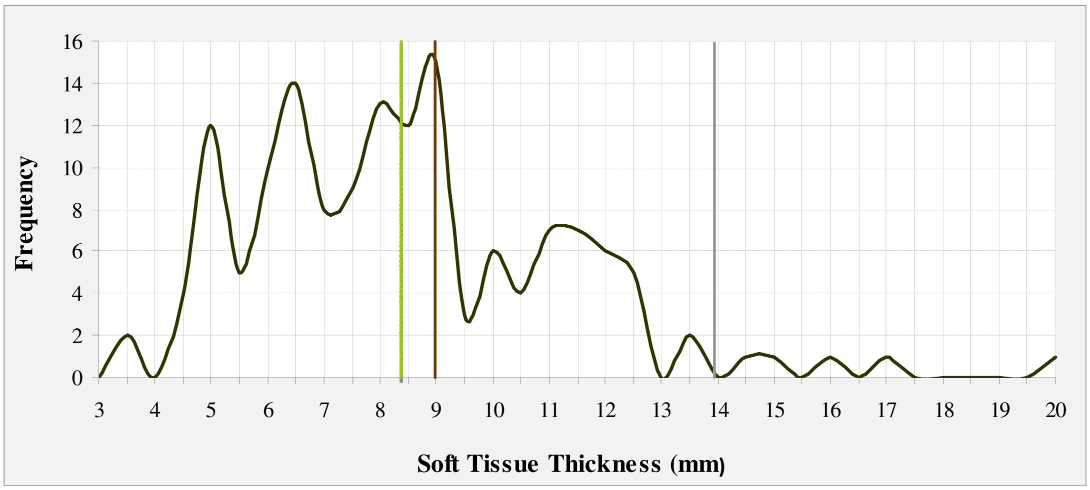

Figure 4.21 Distribution of the measurements of S – Lateral zygomatic arch. The green line indicates the mean, brown line the mode, and grey line the upper limit of 2SD

This value from Manhein *et al.* (2000) of 6.40 mm (p = 0.002) and Rhine and Campbell (1980) of 9.50 mm (p = 0.000), both show a statistically significant difference from that of the current study. The value of Phillips and Smuts (1996) of 9.30 mm is not significantly different.

T – Supra-glenoid

This is a measurement superior to the external acoustic meatus. It was measured in 151 individuals. The mean value was 12.01 (SD = 2.19, range = 11.6). The mode, 11.3, and mean and are fairly good representations of each other. Figure 4.22 shows the frequency distribution of the measurements for T. Most of the measurements of the study population are concentrated around the mean, resulting in a fairly normal distribution, except for the outliers seen above 2SD from the mean.

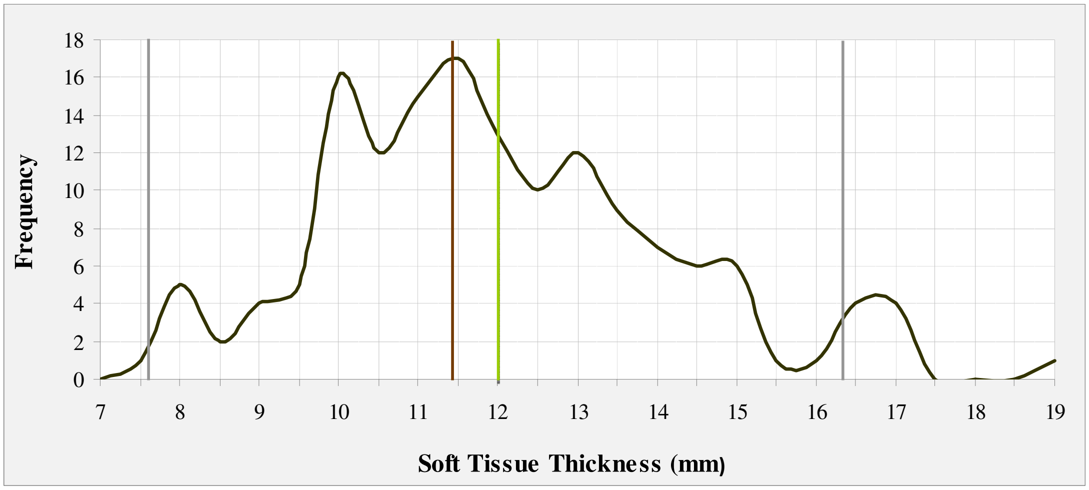

Figure 4.22 Distribution of the measurements of T - Supra-glenoid. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

This value was significantly higher from that of Manhein *et al.* (2000) of 6.40 mm ($p = 0.000$), Phillips and Smuts (1996) of 8.44 mm ($p = 0.002$) and Rhine and Campbell (1980) of 11.50 mm ($p = 0.005$).

U – Area of the parotid

This measurement was taken on the ramus of the mandible, as described in Chapter 3. It was measured in 145 individuals. The mean value was 19.51 mm (SD = 3.69, range = 19.8). No value is indicated as the mode, as there were several values that occurred as the most frequent value in the data series. Figure 4.23 shows the frequency distribution of the measurements for U. Most of the measurements of the study population are concentrated around the mean, except for the outliers seen below and above 2SD from the mean. This measurement has not been included in other studies.

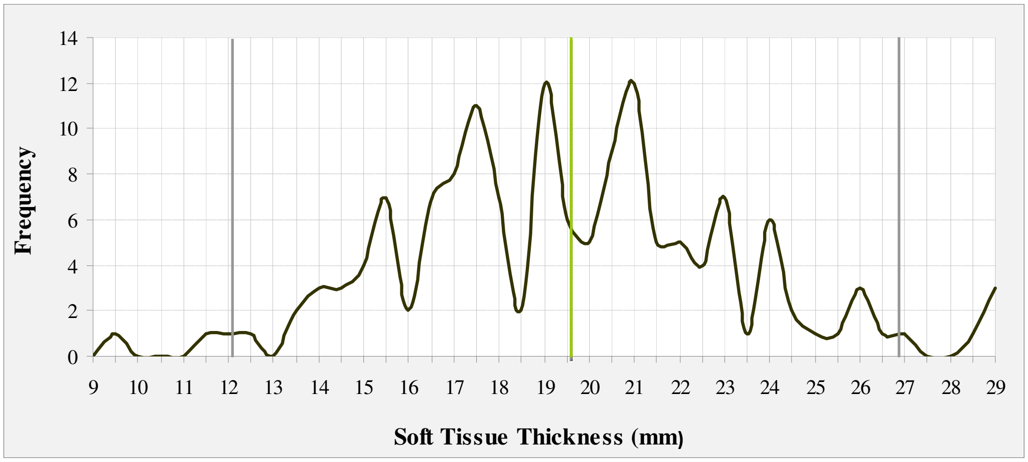

Figure 4.23 Distribution of the measurements of U – Area of the parotid. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

V – Mid-masseteric

This measurement was taken on the ramus of the mandible, as described in Chapter 3. It was measured in 128 individuals. The mean value was 22.38 mm (SD = 3.71, range = 19.8). Figure 4.24 shows the frequency distribution of the measurements for V. No value is indicated as the mode, as there were several values that occurred as the most frequent value in the data series. Most of the measurements of the study population are concentrated around the mean, except for the one outlier below and outliers above 2SD from the mean. This measurement has not been included in other studies.

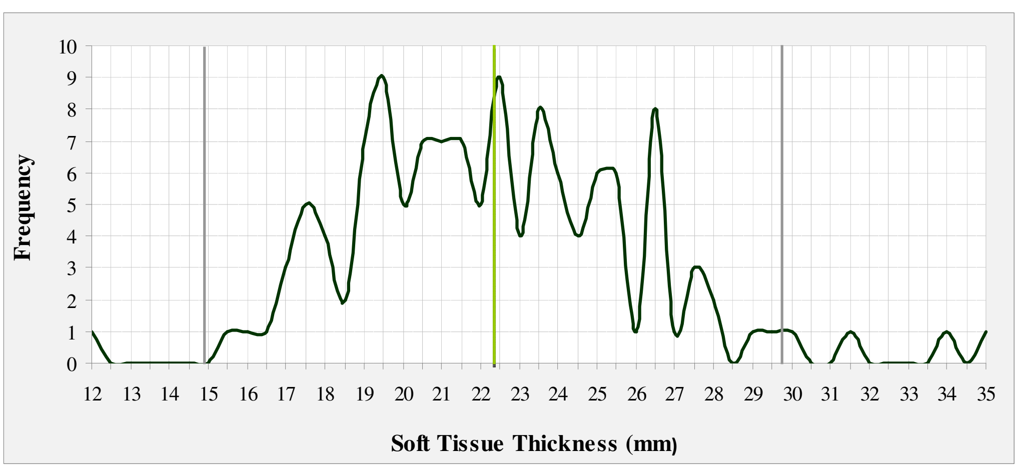

Figure 4.24 Distribution of the measurements of V – Mid-masseteric. The green line indicates the mean, brown line the mode, and grey lines the lower and upper limits of 2SD

W – Gonion

This measurement was taken on the most lateral point on the angle of the mandible. It was measured in 26 individuals. The mean value was 17.90 mm (SD = 4.35, range = 16.3, mode = 15.6). Figure 4.25 shows the frequency distribution of the measurements for W. A high degree of variation is seen in the study population, thus the distribution is not normal, although most of the values fall within 2SD from the mean.

The value from Rhine and Campbell (1980) of 13.50 mm (p = 0.000) and Phillips and Smuts (1996) of 13.50 mm (p = 0.026) both show a statistically significant difference from that of the current study. The value of Manhein *et al.* (2000) of 18.00 mm is not significantly different from the current study.

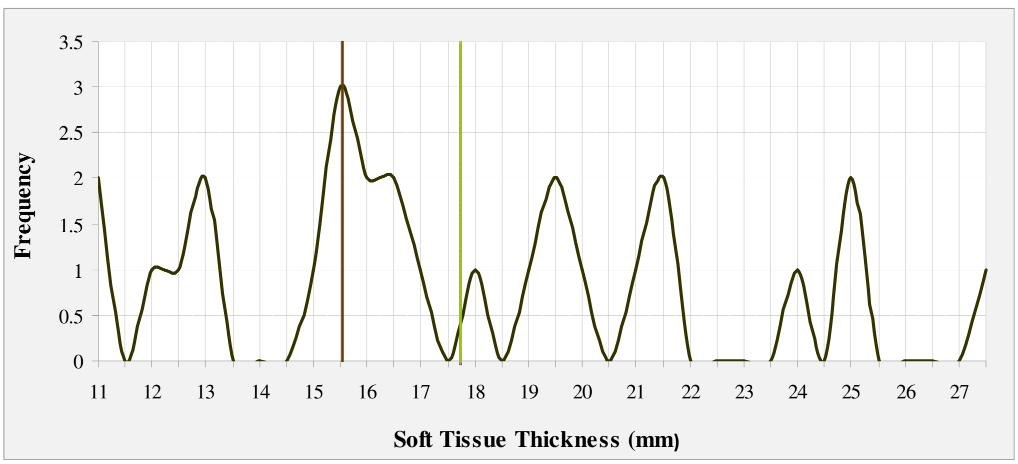

Figure 4.25 Distribution of the measurements of W – Gonion. The green line indicates the mean, brown line the mode, and grey line the upper limit of 2SD

X – Supra M^2

This measurement was taken superior to the second maxillary molar. It was measured in 72 individuals. The mean value was 30.11 mm (SD = 4.43, range = 17.7). The mode, 29.3, is a fairly good reflection of the mean. Figure 4.26 shows the frequency distribution of the measurements for X. A high degree of variation is seen in the study population, thus the distribution is not normal, although most of the values fall within 2SD from the mean.

This value is significantly higher from that of Manhein *et al.* (2000) of 26.60 mm (p = 0.005), Phillips and Smuts (1996) of 11.88 mm (p = 0.000) and Rhine and Campbell (1980) of 20.25 mm (p = 0.000).

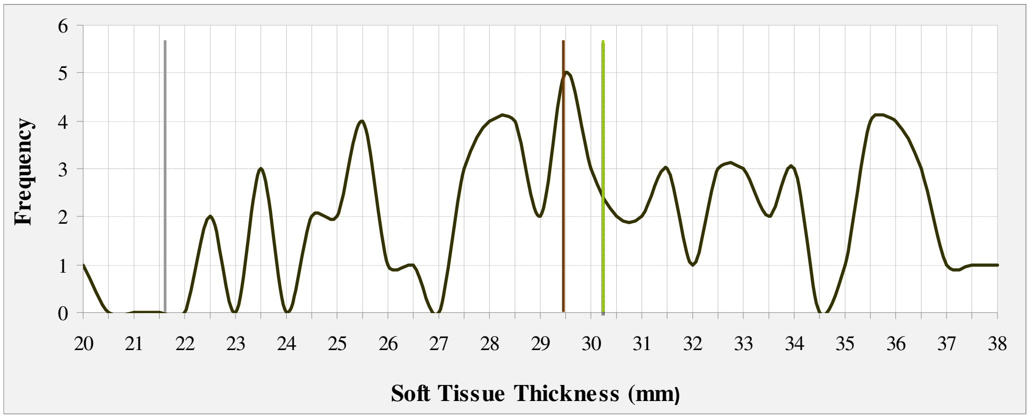

Figure 4.26 Distribution of the measurements of X – Supra M^2. The green line indicates the mean, brown line the mode, and grey line the lower limit of 2SD

Y – Sub M_2

This measurement was taken inferior to the second mandibular molar. It was measured in 25 individuals. The mean value was 21.67 mm (SD = 4.25, range = 15.3). Figure 4.27 shows the frequency distribution of the measurements for X. No value is indicated as the mode, as there were several values that occurred as the most frequent value in the data series. A high degree in variation of the measurement for the sub M_2 is seen in the study population, although all the values fall within 2SD from the mean.

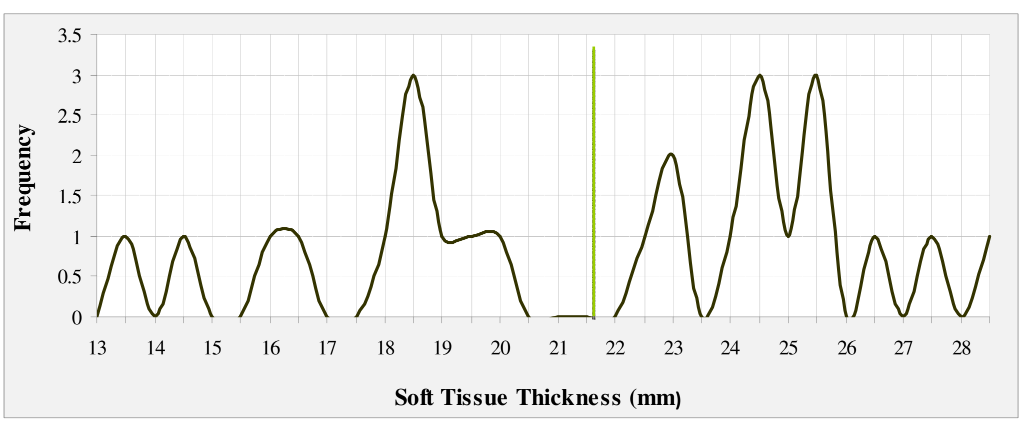

Figure 4.27 Distribution of the measurements of X – Sub M_2. The green line indicates the mean

This value is significantly different from that of Rhine and Campbell (1980) of 17.00 mm (p = 0.000) and Phillips and Smuts (1996) of 11.88 mm (p = 0.026). The value of Manhein *et al.* (2000) of 21.70 mm is not significantly different from the current study.

Z – Occlusal line

This is a measurement on the ramus of the mandible in line with the occluding surface of the teeth. It was measured in 44 individuals. The mean value was calculated as 21.60 mm (SD = 3.93, range 17.1). The mode, 22.2, and mean are fairly good representations of each other. Figure 4.28 shows the frequency distribution of the measurements for T. Most of the measurements of the study population are concentrated around the mean, although outliers are seen above 2SD from the mean.

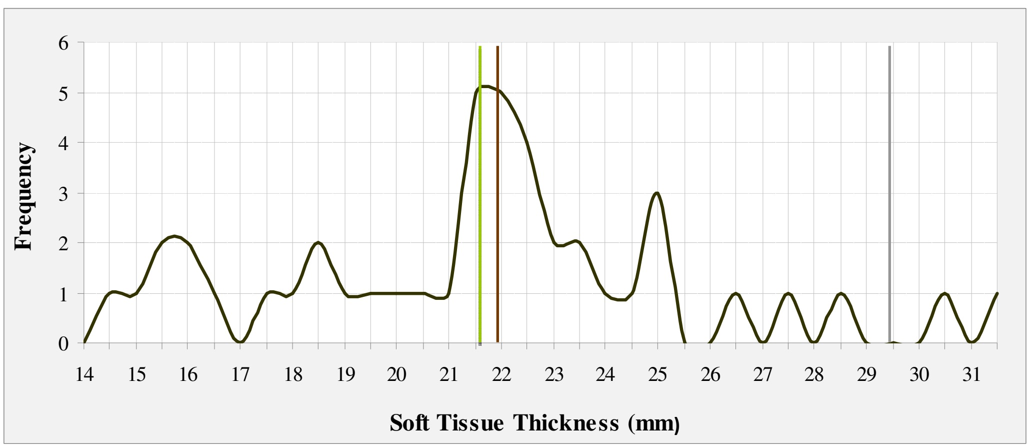

Figure 4.28 Distribution of the measurements of Z – Occlusal line. The green line indicates the mean, brown line the mode, and grey line the upper limit of 2SD

This value is not significantly different from Phillips and Smuts (1996) of 21.26 mm, but is different from that of Rhine and Campbell (1980) of 19.25 mm (p = 0.0003). The study by Manhein *et al.* (2000) has not included this measurement.

4.3 INTRA- AND INTER-OBSERVER REPEATABILITY

In data collection, it is of interest to control the variability of measurements and to evaluate the measurement precision, that is, the inter- and intra-observer reliability, which is reflected in repeatability or reproducibility (Ferrante and Cameriere 2009). The intra-observer repeatability of each measurement was calculated using the intra-class correlation (ICC) from measurements of 22 CT scans that were repeated by the investigator. The inter-observer reliability was calculated again using the ICC, but from measurements on 29 CT scans that were done by a colleague. The means for the different data sets were also compared by the Student's *t*-test. Tables 4.3 and 4.4 show the ICC coefficient values as well as the *t*-values from the Student's *t*-test for the intra- and inter-observer testing respectively. Reading 1 in Tables 4.3 and 4.4 is the values from the current study. Reading 2 in Table 4.3 indicates the values from the measurements taken by the investigator the second time, and reading 3 in Table 4.4 indicates the values from the measurements by the independent observer.

The correlation coefficient evaluates the degree to which pairs of observations agree with each other (Ferrante and Cameriere 2009). Thus the ICC is an indication of how well the measurements correlate, per pair, in each set when measured the first time, then again the second time. Since the correlation coefficient measures a linear relationship, the coefficient values are bound by one, with one being a perfect agreement or correlation, and consequently, no statistical significant differences between the paired sets of measurements (Ferrante and Cameriere 2009). This means: the closer to one the higher the reliability indicating repeatability of the measurements. According to Allan (1982), when a coefficient falls between 0.75 and 0.99, the sets of data are said to have a high degree of correlation. All the measurements in Tables 4.3 and 4.4 that are indicated with green fall within this range. Measurements that fall within a range of 0.5 – 0.74 are classified as a moderate degree of correlation, or within a range of 0.25 – 0.49, a low degree of correlation (Allan 1982). The measurements that showed the highest intra-observer repeatability were that of the lower incisor (JJ; 0.904) and lateral zygomatic arch (S; 0.919) measurements. Measurements that did not correlate well were that of the mid lower lip margin (J; 0.432), frontal eminence (N; 0.425), glabella (B; 0.504), mid-philtrum (H; 0.526) and zygomaxillare (R; 0.553), indicating that these could not be re-measured by the original investigator with a high degree of reliability.

The second observer (Table 4.4.), however, was able to re-measure all the dimensions with precision. The highest ICC values were calculated for the sub-orbital (Q; 0.930), lateral zygomatic arch (S; 0.946), mid-masseteric (V; 0.924) and occlusal line (Z; 0.922) measurements. With the inter-observer repeatability the measurements for the lateral supra-labiale (0.686) and mid-philtrum (0.545) landmarks appeared to be the most unreliable. In general, there is little correlation between the variables that were difficult to repeat between the original observer (intra-observer) and the second observer (inter-observer). This finding is difficult to explain, but may be due to small differences in how the observer(s) used the measurement device (Ferrante and Cameriere 2009), the fact that the sample measured by the two observers was not exactly the same, and it is possible that a few more ambiguous cases were included in the sample of the original observer.

For all of the measurements for the intra- and inter-observer repeatability, the differences of the means between the two data sets are less than 1 millimetre. In reality this difference is quite small, and the effect thereof most likely trivial. To determine whether difference between the means of the two samples is significant on a statistical level, the Student's *t*-test was used. According to this only the difference for N – Frontal Eminence (0.914mm) and P – Supra-orbital (0.666mm) for the intra-observer repeatability (Table 4.3) is calculated as statistically significantly different. Still, these differences remain less than 1 mm, and the physical effect thereof can only be determined when applied practically.

Table 4.3 Intra-observer repeatability expressed by the intra-class correlation coefficient (ICC)

Measurement	Reading	Number of pairs	Mean (SD)	ICC	p-value (tabular t value)
A Supra-glabella	1 2	21	4.410 (0.858) 4.371 (0.819)	0.811	0.147 (1.68)
B Glabella	1 2	21	6.219 (1.298) 6.105 (1.295)	0.504	0.286 (1.68)
C Nasion	1 2	19	5.005 (1.273) 5.042 (1.471)	0.760	0.083 (1.69)
D End of nasals	1 2	18	2.461 (0.918) 2.650 (0.819)	0.833	0.651 (1.69)
E Lateral nasal	1 2	21	4.095 (1.493) 3.771 (1.486)	0.727	0.704 (1.68)
F Lateral supra-labiale	1 2	9	8.778 (0.657) 8.322 (1.258)	0.607	0.963 (1.75)
G Mental tubercle	1 2	5	11.220 (2.203) 10.920 (2.510)	0.782	0.201 (1.86)
H Mid-philtrum	1 2	21	10.090 (1.558) 10.090 (1.496)	0.526	0.000 (1.68)
I Mid upper lip margin	1 2	20	12.075 (2.136) 12.440 (2.057)	0.788	0.550 (1.68)
II Upper incisor	1 2	15	10.520 (2.002) 10.347 (2.552)	0.863	0.207 (1.70)
J Mid lower lip margin	1 2	18	13.472 (2.202) 14.200 (1.203)	0.432	1.230 (1.69)
JJ Lower incisor	1 2	14	12.657 (1.298) 12.714 (1.311)	0.904	0.116 (1.69)
K Supra-mentale	1 2	18	12.856 (2.299) 12.661 (2.183)	0.886	0.260 (1.69)
L Mental eminence	1 2	16	10.050 (1.780) 10.163 (2.250)	0.795	0.157 (1.69)
M Beneath chin	1 2	11	6.100 (1.448) 5.918 (1.465)	0.757	0.293 (1.73)
N Frontal eminence	1 2	21	4.533 (0.981) 3.619 (0.961)	0.425	3.051 (1.68)
O Fronto-temporale	1 2	21	4.424 (1.450) 4.071 (1.416)	0.733	0.797 (1.68)
P Supra-orbital	1 2	21	6.776 (1.232) 6.110 (1.295)	0.847	1.709 (1.68)
Q Sub-orbital	1 2	18	6.189 (1.803) 5.811 (1.730)	0.824	0.641 (1.69)
R Zygomaxillare	1 2	15	18.247 (2.719) 17.247 (2.677)	0.553	1.015 (1.70)
S Lateral zygomatic arch	1 2	20	7.465 (2.879) 7.045 (3.041)	0.919	0.449 (1.68)
T Supra-glenoid	1 2	20	12.150 (1.913) 11.935 (2.093)	0.658	0.339 (1.68)
U Area of the parotid	1 2	19	18.700 (2.790) 18.453 (2.655)	0.795	0.280 (1.68)
V Mid-masseteric	1 2	17	20.988 (2.409) 20.735 (3.112)	0.802	0.265 (1.69)
W Gonion	1 2	4	16.325 (3.083) 17.800 (3.896)	0.635	0.594 (1.94)
X Supra M^2	1 2	9	28.667 (3.545) 27.111 (5.171)	0.813	0.744 (1.75)
Y Sub M_2	1 2	4	19.375 (5.016) 19.350 (4.507)	0.741	0.007 (1.94)
Z Occlusal line	1 2	6	20.700 (3.958) 21.683 (3.807)	0.785	0.439 (1.81)

Green indicates a high degree of correlation.
Grey indicates a statistically significant difference between the means.

Table 4.4 Inter-observer repeatability expressed by the intra-class correlation coefficient (ICC)

Measurement	Reading	Number of pairs	Mean (SD)	ICC	p-value (tabular t value)
A **Supra-glabella**	1 3	29	4.876 (1.144) 4.979 (1.058)	0.796	0.358 (1.67)
B **Glabella**	1 3	29	6.662 (1.184) 6.324 (1.191)	0.773	1.083 (1.67)
C **Nasion**	1 3	26	5.846 (1.341) 6.038 (6.038)	0.741	0.523 (1.67)
D **End of nasals**	1 3	28	2.982 (1.384) 2.882 (1.169)	0.813	0.292 (1.67)
E **Lateral nasal**	1 3	29	4.393 (1.254) 4.228 (1.310)	0.856	0.492 (1.67)
F **Lateral supra-labiale**	1 3	24	9.792 (1.733) 10.271 (1.718)	0.686	0.962 (1.68)
G **Mental tubercle**	1 3	9	12.244 (2.939) 11.589 (3.330)	0.817	0.443 (1.75)
H **Mid-philtrum**	1 3	28	10.746 (1.082) 10.993 (1.096)	0.545	0.847 (1.67)
I **Mid upper lip margin**	1 3	27	13.093 (1.643) 13.511 (1.703)	0.783	0.919 (1.67)
II **Upper incisor**	1 3	26	10.188 (1.349) 9.631 (1.863)	0.724	1.236 (1.67)
J **Mid lower lip margin**	1 3	26	14.681 (1.717) 15.177 (1.686)	0.720	1.051 (1.67)
JJ **Lower incisor**	1 3	25	13.352 (1.407) 13.444 (1.467)	0.894	0.226 (1.68)
K **Supra-mentale**	1 3	25	12.396 (2.268) 12.624 (2.327)	0.875	0.351 (1.67)
L **Mental eminence**	1 3	19	10.911 (2.231) 10.500 (2.129)	0.800	0.580 (1.69)
M **Beneath chin**	1 3	12	6.625 (1.843) 6.892 (1.859)	0.841	0.353 (1.72)
N **Frontal eminence**	1 3	28	5.154 (1.142) 5.289 (1.435)	0.714	0.392 (1.67)
O **Fronto-temporale**	1 3	28	5.214 (1.460) 5.321 (1.720)	0.878	0.251 (1.67)
P **Supra-orbital**	1 3	29	7.210 (1.350) 7.210 (1.432)	0.849	0.000 (1.67)
Q **Sub-orbital**	1 3	29	7.490 (2.745) 7.631 (2.910)	0.930	0.190 (1.67)
R **Zygomaxillare**	1 3	19	19.489 (3.743) 19.547 (4.140)	0.893	0.045 (1.69)
S **Lateral zygomatic arch**	1 3	29	9.131 (3.373) 9.024 (3.644)	0.946	0.116 (1.67)
T **Supra-glenoid**	1 3	29	12.807 (2.431) 12.762 (3.138)	0.780	0.061 (1.67)
U **Area of the parotid**	1 3	29	19.466 (3.841) 19.710 (4.441)	0.868	0.225 (1.67)
V **Mid-masseteric**	1 3	28	22.196 (4.121) 21.661 (4.416)	0.924	0.469 (1.67)
W **Gonion**	1 3	10	16.500 (4.836) 16.170 (5.320)	0.832	0.145 (1.73)
X **Supra M^2**	1 3	26	29.792 (4.027) 28.812 (5.028)	0.876	0.776 (1.67)
Y **Sub M_2**	1 3	12	21.550 (4.038) 22.217 (4.341)	0.768	0.390 (1.72)
Z **Occlusal line**	1 3	22	21.745 (4.575) 21.545 (4.921)	0.922	0.140 (1.68)

Green indicates a high degree of correlation.

4.4 MORPHOLOGICAL ANALYSIS

4.4.1 Reconstructions

The completed reconstructions were photographed from three angles to give full frontal, three-quarter (30˚ rotation of the face) and left profile views. These can be seen in Figures 4.29 to 4.34. The photographs for the reconstructions on the same skull were grouped together for easy comparison when using different databases for the source of STT values. The same was done for the lateral profile and three-quarter rotation photographs.

This study focused on the influence of tissue thicknesses on the results of facial reconstruction. These tissue thicknesses were expected to only influence the face shape, and not the eyes, nose and ears. It was therefore attempted to keep the shapes and sizes of the eyes, nose and ears of the four reconstructions the same, so that the greatest difference would come from the different tissue thickness measurements of the databases used and not in the shapes of other structures. However, many measurements were taken on landmarks around the mouth, therefore the shape and size of the mouth and lips are still dependent on tissue thickness data, and may appear different on the four reconstructions.

On the analysis of Skull A prior to reconstruction, the shape of some features could be pre-determined. The low and wide orbits, with a sharp supra-orbital rim overhanging to the lateral sides, indicated eye folds of the upper eyelids to start near the inner angle of the upper eyelid and to be pronounced laterally (İşcan and Helmer 1993). The eyebrows follow the upper orbital margin, and therefore would not have a greatly curved shape, but a rather flat appearance. Nasal shape was determined to be flat and wide, with a down-turned base and rounded tip. The position of the tip of the nose was approximated by the intersection of two lines; one projected along the lower third from the ridge of the nasal bones and the other a continuation form the direction of the tip of the nasal spine (İşcan and Helmer 1993; Rogers 1987; Wilkinson 2004). A curve fitted to the intersection of these lines should locate the nose tip (Rogers 1987). As there was no bony indication to the shapes of the ears, the auricles were created as average shaped ears according to the method describe by Taylor (2001). Because no bony indication of the hairline and hair style exists, the indication of hair was for adding realistic appearance to the face only.

On analysis of Skull B prior to reconstruction, it was determined that, based on the high orbit, the eyes would be almond shaped, with an absent eye fold on the upper eyelid. Following the arch of the upper orbital margin, the eyebrows would have a more curved shape. The nasal bridge was determined to be rather narrow with an up-turned nasal spine. Again, as there was no bony indication of the shapes of the ears, hairline and hairstyles, these were only added to contribute to the realistic appearance of the reconstruction.

In general, the reconstructions appeared fairly similar, but some subtle differences could be observed. The most obvious difference between the various reconstructions, as could be expected according the areas showing the greatest statistical differences in the STT values, were in the areas around the mouth, cheeks, chin and mandibular ramus.

The reconstructions that were made with tissue thicknesses from the current study have a very strong, square and broad jaw line. The area around the cheeks and mouth is much fuller and the mouth appears more relaxed. The reconstructions with tissue thicknesses from Manhein *et al.* (2000) also have this appearance, but not with as broad a jaw as with the values form the current study. The broader jaws are especially noticeable in Figure 4.32, when comparing photographs (i) and (ii) to photographs (iii) and (iv). The narrower face resulting from tissue thicknesses from Manhein *et al.* (2000) is easily seen when viewed from the front and comparing photograph (ii) to photograph (i) in Figures 4.29 and 4.32.

The reconstructions with tissue thicknesses from Philips and Smuts (1996) have a relatively strong and square jaw seen on the frontal view (Figure 4.29 (iii)), but the area around the mouth has a tense expression giving a pouting look with hollow cheeks, especially seen in the three-quarter view (Figures 4.31 (iii) and 4.34 (iii)). The lips in these reconstructions extend more to the front than the rest of the reconstructions, and give the reconstructions a very unnatural appearance.

Reconstructions with tissue thicknesses from Rhine and Campbell (1980), those currently used in South Africa, give a much sharper jaw line, as well as the hollow cheeks and pouting lips, best seen on the frontal and three-quarter angles (Figures 4.29 (iv), 4.31 (iv), 4.32 (iv) and 4.34 (iv)). The reconstruction from Rhine and Campbell's tissue thicknesses on Skull B (Figure 4.34 (iv)) also has a somewhat unnatural appearance and a pouting expression, rather than a relaxed mouth. When viewing the reconstructions from a lateral profile angle (Figures 4.30 and 4.33), the reconstructions from all the STT databases appear to show the same amount of prognatism (which was expected, as this is mainly influenced by the protrusion of the teeth and jaws and less by the tissue thickness), with the major differences being the appearance of the lips. Even though the lips are a subjective feature to reconstruct, the STT values around the mouth gives enough guidance to how much the lips can protrude. The reconstructions with the most unnatural appearing, pouting lips are those using the Phillips and Smuts (1996) data.

The areas with the least difference were that of the forehead, lateral sides of the eyes and zygomae. Apart from the reconstructor's attempt to keep the eyes, nose and ears as similar as possible to rule out the effect that these features may have on the appearance, these were also the areas to show least statistical difference between the different STT databases.

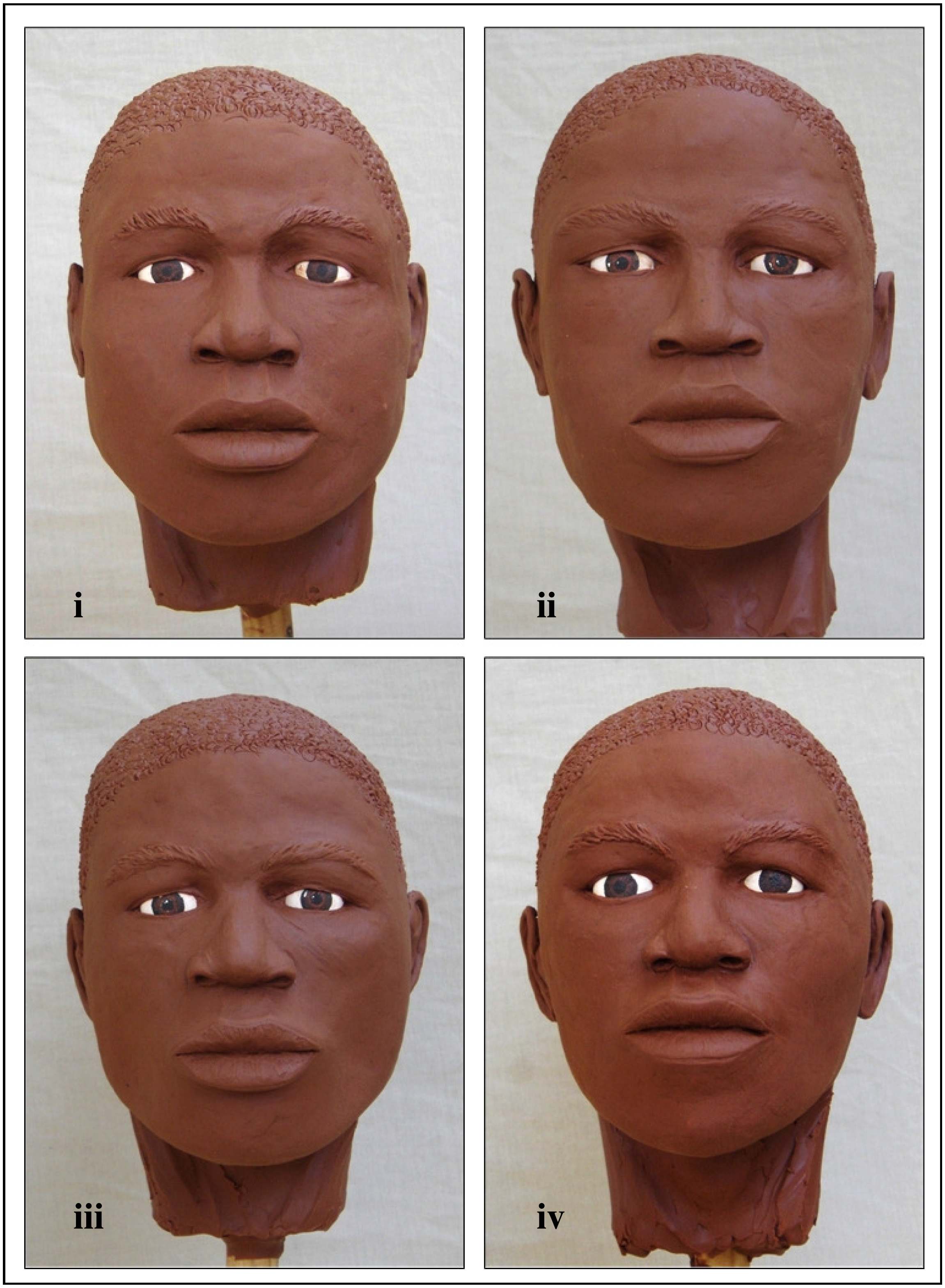

Figure 4.29 Frontal view of reconstructions on Skull A with tissue thickness values from four different databases: i – Current study; ii – Manhein *et al.* (2000); iii – Phillips and Smuts (1996); iv – Rhine and Campbell (1980). These should be compared to Individual 1 (Figure 4.35 A)

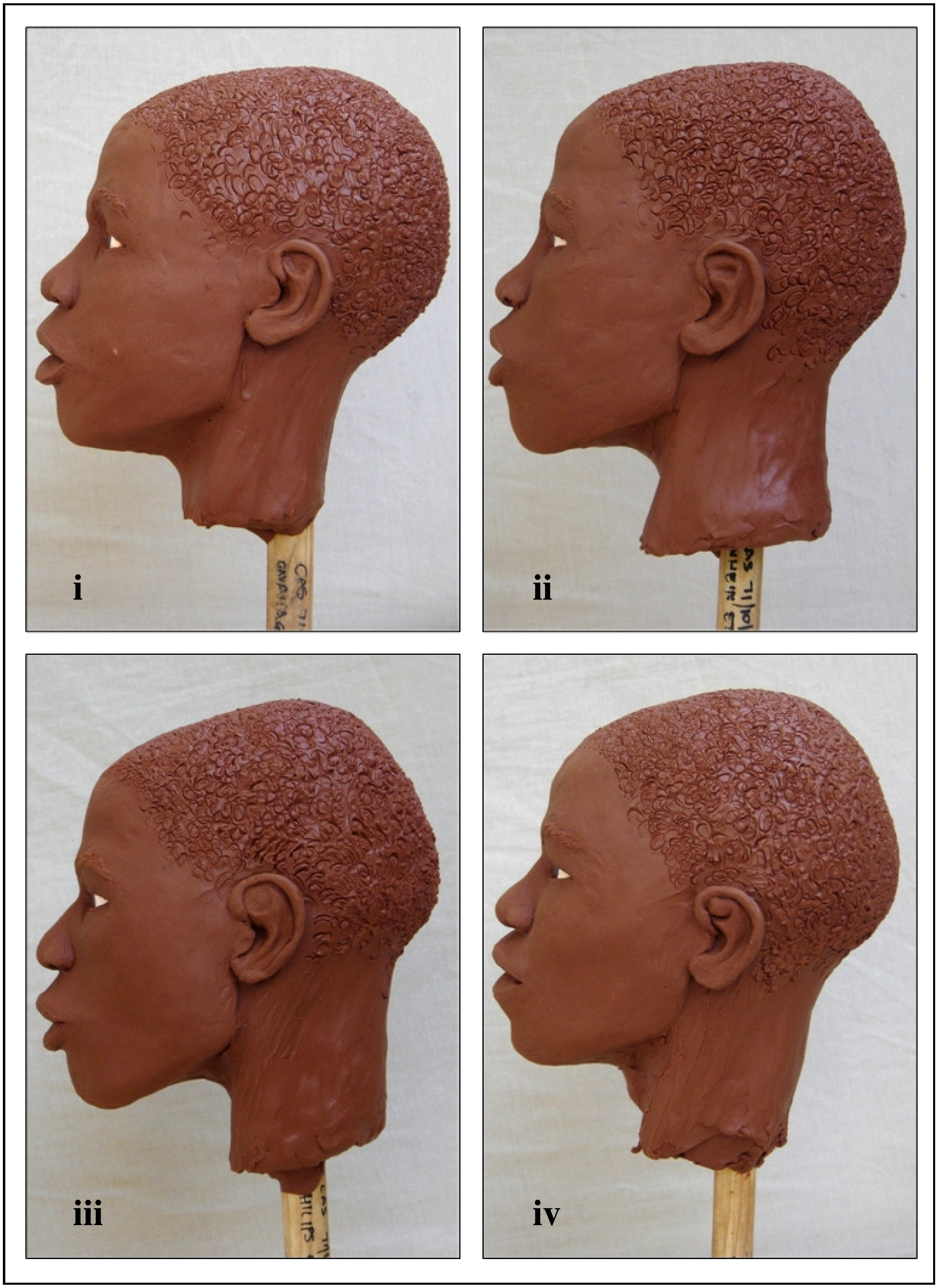

Figure 4.30 Lateral view of reconstructions on Skull A with tissue thickness values from four different databases: i – Current study; ii – Manhein *et al.* (2000); iii – Phillips and Smuts (1996); iv – Rhine and Campbell (1980). These should be compared to Individual 1 (Figure 4.35 A)

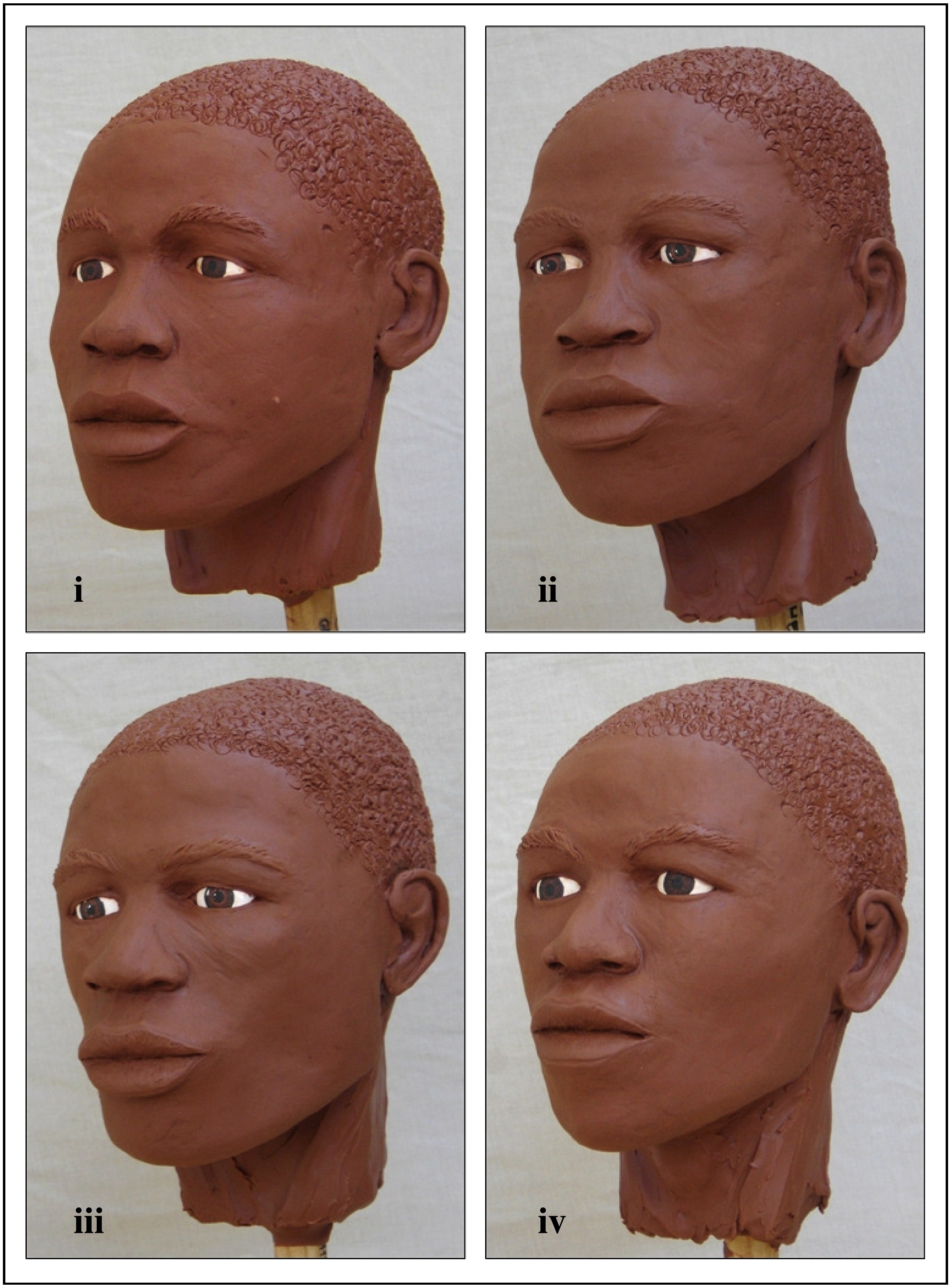

Figure 4.31 Three-quarter rotation view of reconstructions on Skull A with tissue thickness values from four different databases: i – Current study; ii – Manhein *et al.* (2000); iii – Phillips and Smuts (1996); iv – Rhine and Campbell (1980). These should be compared to Individual 1 (Figure 4.35 A)

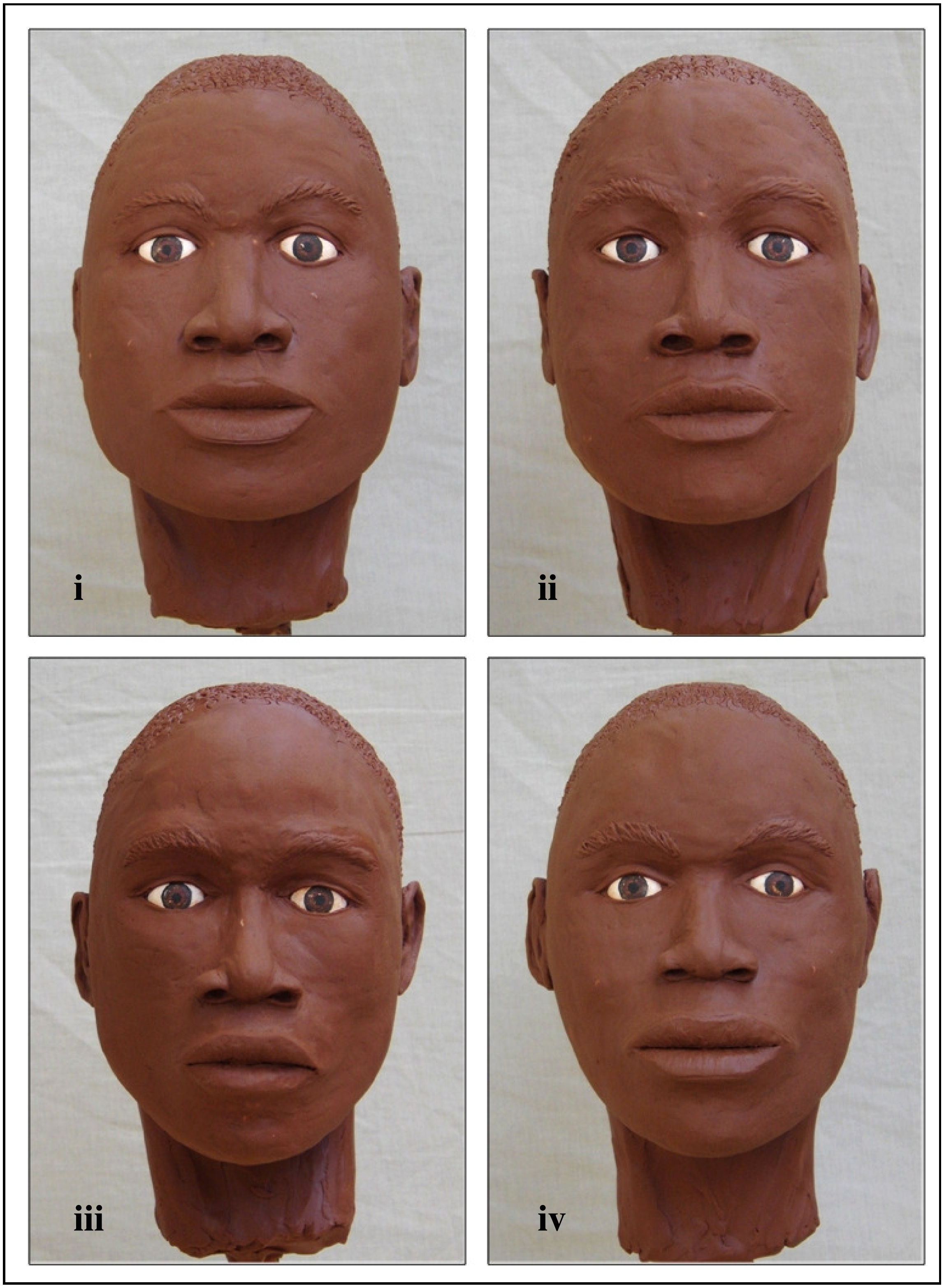

Figure 4.32 Frontal view of reconstructions on Skull B with tissue thickness values from four different databases: i – Current study; ii – Manhein *et al.* (2000); iii – Phillips and Smuts (1996); iv – Rhine and Campbell (1980). These should be compared to Individual 2 (Figure 4.35 B)

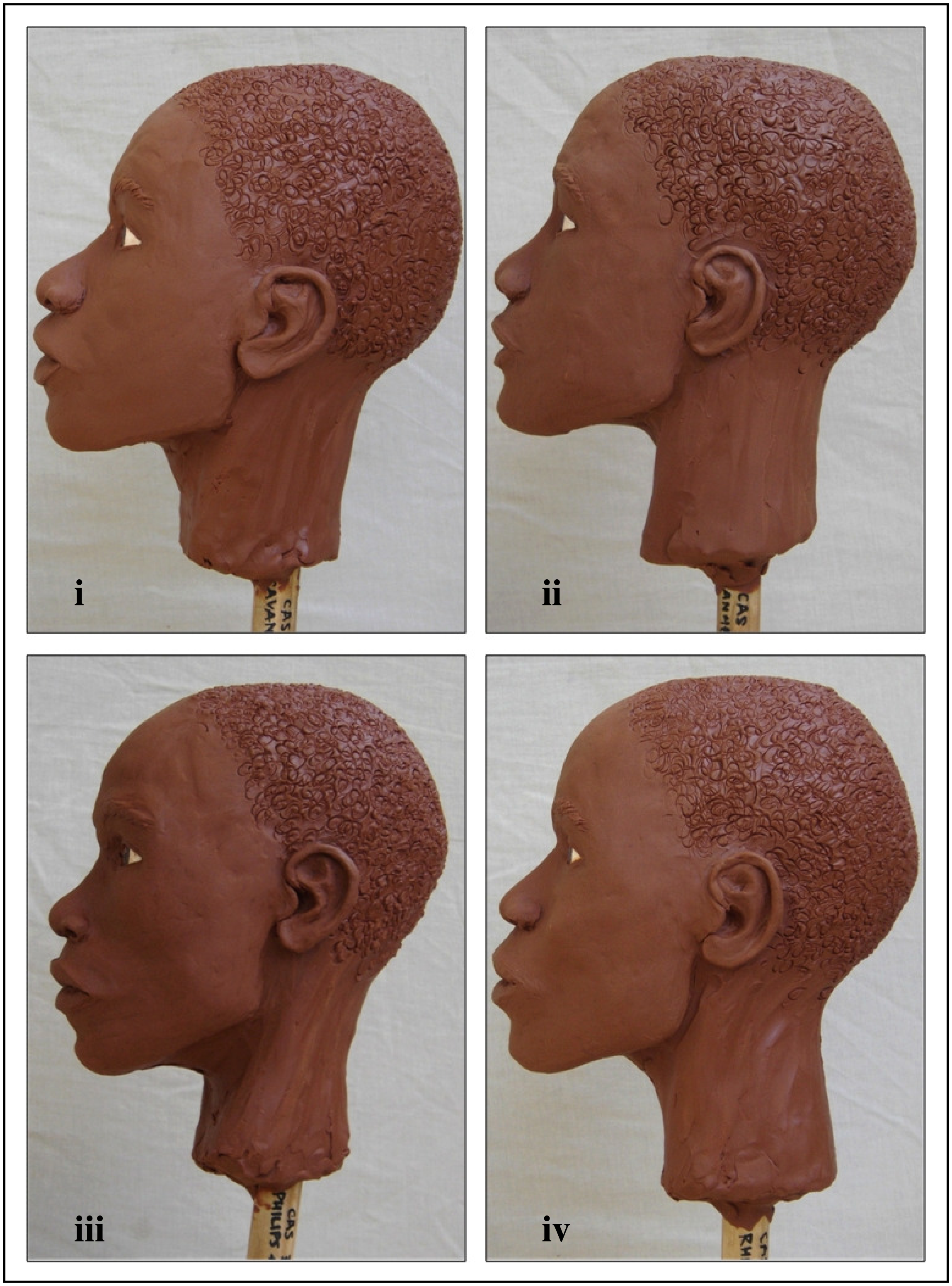

Figure 4.33 Lateral view of reconstructions on Skull B with tissue thickness values from four different databases: i – Current study; ii – Manhein *et al.* (2000); iii – Phillips and Smuts (1996); iv – Rhine and Campbell (1980). These should be compared to Individual 2 (Figure 4.35 B)

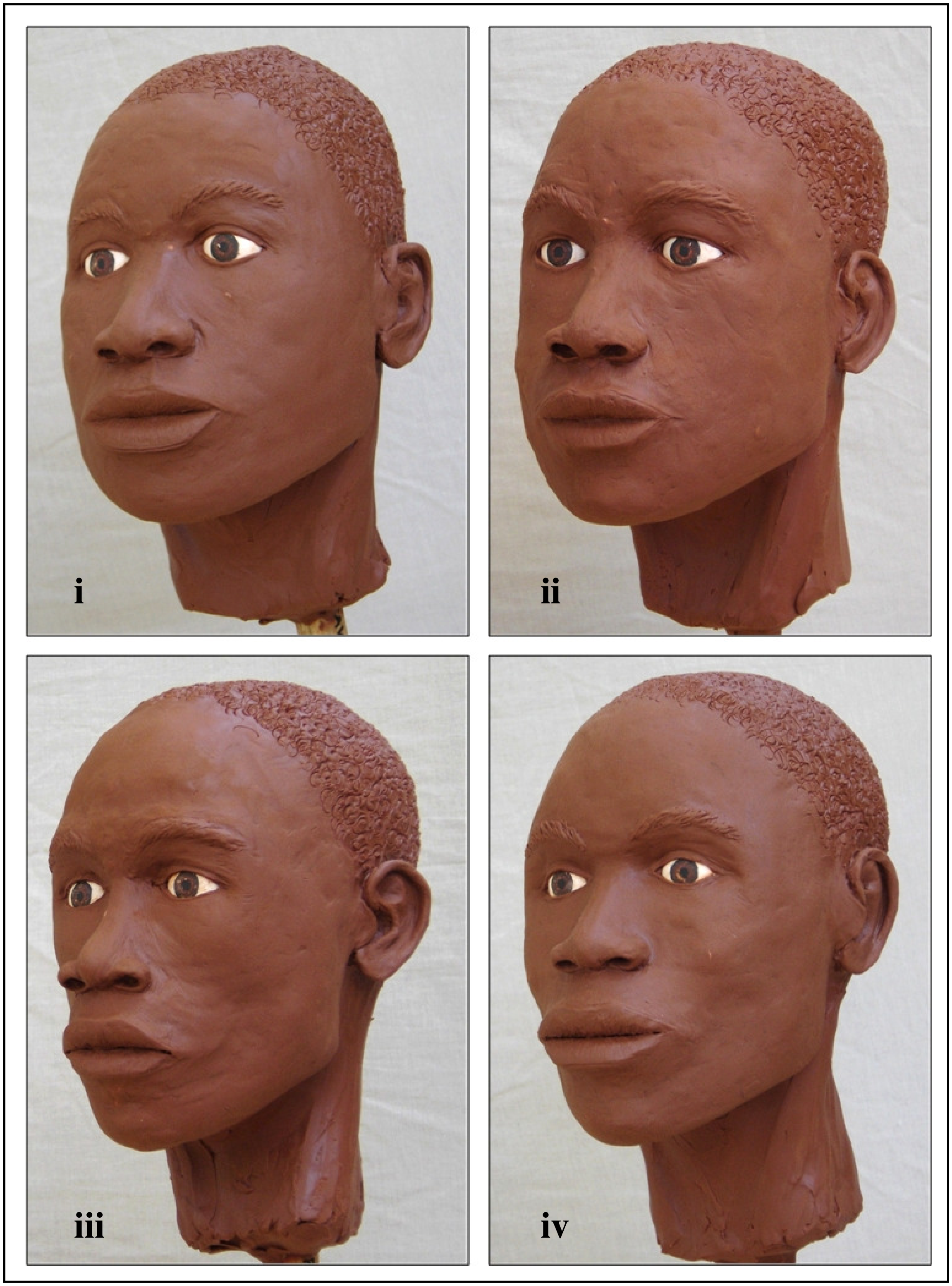

Figure 4.34 Three-quarter rotation view of reconstructions on Skull B with tissue thickness values from four different databases: i – Current study; ii – Manhein *et al.* (2000); iii – Phillips and Smuts (1996); iv – Rhine and Campbell (1980). These should be compared to Individual 2 (Figure 4.35 B)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

The photographs of the actual individuals are shown in Figure 4.35. Skull A matches Individual 1, and Skull B matches Individual 2. Individual 1 appears to actually have the strong square jaw line and relaxed mouth as seen in the reconstructions, and shows a fair resemblance to the reconstruction using data from the current study. Although difficult to judge, it also has a fair resemblance to the reconstruction from Manhein *et al.* (2000). From the front, the reconstruction from Phillips and Smuts (1996) appears to also have a good resemblance (Figure 4.29 (iii)), but is very different on the three-quarter photograph (Figure 4.31 (iii)), which does not truly fit the facial profile of Individual 1.

For Individual 2, there is not really a reconstruction that gives a true overall resemblance. This individual appears to have a sharper jaw line with the almost pouting expression and prominent zygomae. This is resembled by the reconstructions using the Phillips and Smuts (1996) or Rhine and Campbell (1980) values, although these reconstructions do not seem to give a very relaxed and normal look. To give a more objective assessment of the outcomes of the reconstructions, identification sessions were used with outside independent observers, and will be discussed in section 4.4.2.

Figure 4.35 Photographs of the actual individuals. A – Individual 1; B – Individual 2

In order to better demonstrate the observed differences, outlines of the shapes of the completed reconstructions were traced from photographs that were taken of the four different reconstructions for every skull, in the same positions. Figures 4.36 and 4.37 show these outlines when superimposed. The black outlines indicate the shape of the reconstructions with tissue thicknesses developed in the current study. The blue outlines indicate the tissue thicknesses developed by Manhein *et al.* (2000), green by Rhine and Campbell (1980) and red by Phillips and Smuts (1996).

The same differences seen in the reconstructions can be noted in these outline overlays. For Skull A (Figure 4.36), from the front, the greatest difference lies in the shape of the lower face, with that of Manhein *et al.* (2000) being significantly narrower than the rest. In the lateral profile, the outlines seem very similar, except for the lower lip that appears more padded with STT values of Rhine and Campbell (1980). In the three-quarter rotation view, the protruding (pouting) lips are seen with reconstructions using Phillips and Smuts (1996) data.

For Skull B (Figure 4.37), the outlines from STT values of the current study and those of Manhein *et al.* (2000) show the broadest jaw lines when viewed from the front. Manhein *et al.* (2000) shows the broadest jaw line again in the three-quarter profile view. From the lateral profile view, all four outlines seem to be very similar in the areas around the nose, mouth and chin, but the brow ridges and glabella using Rhine and Campbell (1980) data stands out more than the rest.

The outlines for the current study (black outlines) show no features that are more (or less) prominent or defined than any of the other reconstructions (from another STT set). This could indicate that the reconstructions from STT of the current study represent a "normal face" possible for that skull, that is, a good average between the different STT values that are available. The paradox is that people are usually remembered for their differences from the average, that is, for their peculiarities (Aulsebrook 2000).

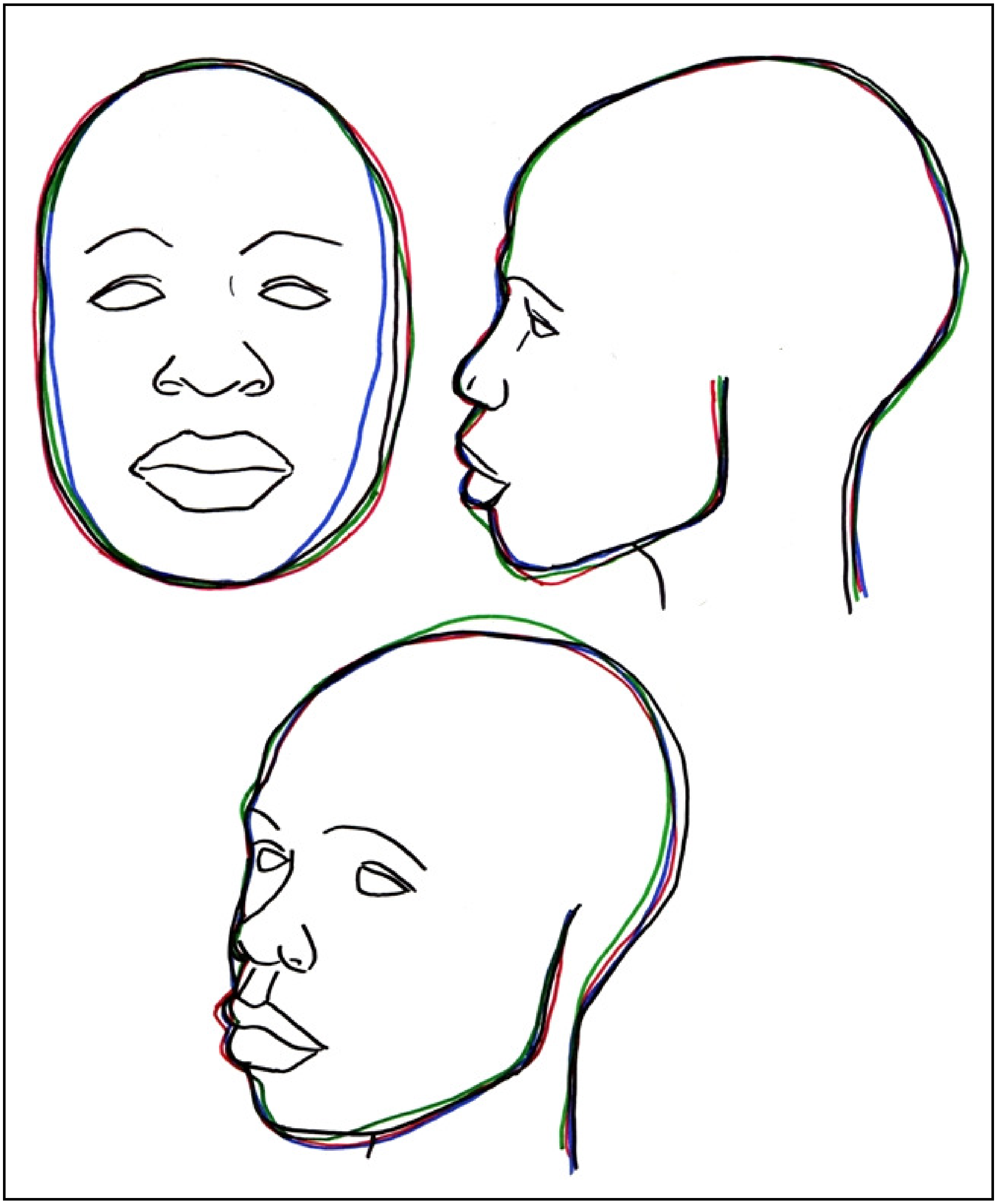

Figure 4.36 Outlines of the shapes of the reconstructions on Skull A from the various tissue thickness databases (Black: Current study, Blue: Manhein *et al.* (2000), Green: Rhine and Campbell (1980), and Red: Phillips and Smuts (1996))

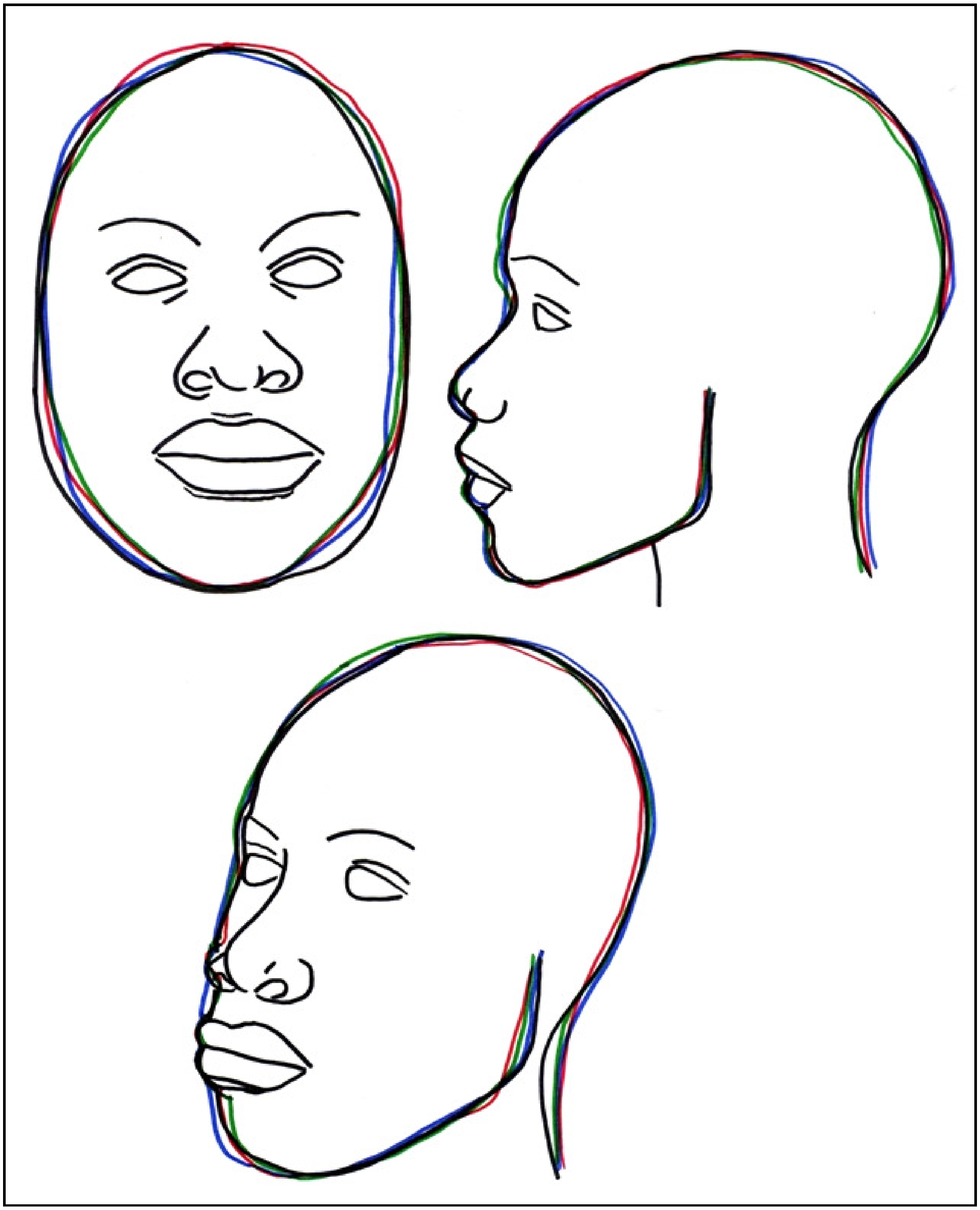

Figure 4.37 Outlines of the shapes of the reconstructions on Skull B from the various tissue thickness databases (Black: Current study, Blue: Manhein *et al.* (2000), Green: Rhine and Campbell (1980), and Red: Phillips and Smuts (1996))

4.4.2 Identification sessions

To determine which one of the four sets of STT produced the best results, and if these are significantly different enough to warrant the use of population-specific STT values, the outcomes need to be quantified. Therefore, identification sessions were held and identification rates were calculated from the results for each of the four sets of STT for both skulls.

During the first identification session, 30 observers were asked to identify the most likely match for each reconstruction from a series of photographs, which included the photographs of the actual individuals and 18 photographs of black female volunteers. The same series of 20 photographs were used at each reconstruction. Details are given in Chapter 3 (Materials and methods). When a photograph was chosen as a match (perfect or possible) to a reconstruction, it scored one point (Appendix E). Identification rates were calculated for each photograph by dividing the score for each photograph at a reconstruction by the total score for all photographs at that reconstruction. For example, for Skull A (the reconstruction with values from the current study) the true photograph was chosen as a perfect and possible match a total of 12 times. The remaining 19 photographs altogether were chosen as a match to that same reconstruction 62 times, indicating a total of 74 observations available. Thus, the identification rate of the true positive photograph was 12 out of 74 (16.22%). This was calculated for all 20 photographs at each of the eight reconstructions. These identification rates are shown in Table 4.5.

When the correct photograph was chosen as the match, it was classified as a *true positive identification*, and a photograph other than the true individual, a *false positive identification*. Photograph 16 (Individual 1) was the true positive, that is, the real photograph, of Skull A, and photograph 10 (Individual 2) of Skull B. The identification session was focused on determining the possibility of accurately matching the correct photograph to the reconstruction from a random pool of individuals, and to compare this possibility between the different STT databases. The results of the true positive matches are summarised in Table 4.6.

In Table 4.5, the percentage values highlighted in green are that of the actual photographs at each reconstruction. The percentage values highlighted in grey are that of any photographs (from the false positive matches) that had an identification rate equal to or greater than the true positive photographs. This gives an idea of how well the real photographs fared when compared to the false positives, and if the true positive photographs could be identified at a higher frequency (%) than the false positives.

For Skull A, the reconstruction with the tissue thickness values from the current study produced good results in comparison with the scores for the reconstructions from the other three databases. Where the STT values from the current study were used (reconstruction 1) an identification rate of 16.2 % was scored, that is, the correct photograph was chosen 16.2% of the time by observers, which is more than any of the other photographs. For the reconstructions from tissues thicknesses from Manhein *et al.* (2000) and Phillips and Smuts (1996), the true positives did not score the highest identification rates, but remained within the top scorers for those reconstructions. The identification rate of the reconstruction from Manhein *et al.* (2000) was 7.9%, and was only the third highest score for that reconstruction. Five other photographs produced identification rates equal to or higher than the actual photograph at this reconstruction. The actual photograph at the reconstruction from Phillips and Smuts (1996) produced an identification rate of 11.94 %, which was the second highest rate at that reconstruction. The true positive photograph for the reconstruction from Rhine and Campbell (1980)'s tissue thicknesses produced an identification rate of 9.72%, equal to photographs 10 and 20. Thus, with all other sets of STT values, the correct photograph was selected fairly often, but less or equal than other random photographs. Random individuals 1, 3, 6, 10, 11, 13 and 20 seem to have been similar in appearance to the actual individual. The values from the current study (reconstruction 1) produced the best results for Skull A, although it was only chosen by 16% of observers.

For Skull B, the true positive photograph at the reconstruction from the current study's STT values produced an identification rate of 11.9%, but photograph 17 was selected more often (17.9%). The next best was individual 15, who scored 13.9%. The reconstruction using the Phillips and Smuts (1996) data gave an identification rate of 12.5% for the true positive photograph, as did individual 13. The two reconstructions based on American values scored the best identification rates in their series of photographs. The reconstruction from the Manhein *et al.* (2000) and Rhine and Campbell (1980) data produced rates of 11.8% and 11.9% respectively. Even though this is the highest rate in their own series, the percentage was still lower, albeit by a small fraction, than that scored using the South African data sets. It seems that individuals 12, 15 and 17 could have facial features similar to the actual individual and an even stronger resemblance to the reconstructions than the actual individual.

From Table 4.6 it can be deduced that overall Skull B fared better than Skull A, although the highest single identification rate for a true positive photograph was seen for Skull A, created with STT from the current study.

To assess whether the actual reconstructions were selected statistically significantly more often than the others, the results were analysed by means of a Pearson's Chi-squared test (Table 4.6). Table 4.6 indicates that the actual individuals at Skull A were chosen for the reconstructions with data from the current study ($p<0.05$), as well as with STT-values of Manhein *et al.* (2000) and Phillips and Smuts (1996), statistically significantly more often. At Skull B the actual individuals at reconstructions from the current study, Phillips and Smuts (1996) and Rhine and Campbell (1980) were selected statistically significantly more often ($p<0.05$). The actual individuals at Skull A using Rhine and Campbell (1980) and

Skull B using Manhein *et al.* (2000) STT's were not selected significantly more than the others.

Table 4.5 Identification rates of the 20 photographs for each reconstruction ("Recon"). Man: Manhein *et al.* (2000), P&S: Phillips and Smuts (1996), R&C: Rhine and Campbell (1980)

	Identification rates (%)							
	Skull A				**Skull B**			
Photo	**Recon 1: Current Study**	**Recon 2: Man (2000)**	**Recon 3: P&S (1996)**	**Recon 4: R&C (1980)**	**Recon 1: Current Study**	**Recon 2: Man (2000)**	**Recon 3: P&S (1996)**	**Recon 4: R&C (1980)**
1	9.46%	**13.16%**	2.99%	1.39%	4.48%	10.29%	1.39%	0.00%
2	4.05%	3.95%	4.48%	1.39%	4.48%	5.88%	1.39%	4.48%
3	10.81%	10.53%	**16.42%**	4.17%	5.97%	8.82%	6.94%	0.00%
4	6.76%	3.95%	5.97%	5.56%	10.45%	8.82%	5.56%	10.45%
5	5.41%	3.95%	4.48%	4.17%	2.99%	0.00%	4.17%	0.00%
6	4.05%	7.89%	0.00%	2.78%	2.99%	4.41%	6.94%	2.99%
7	0.00%	1.32%	4.48%	1.39%	2.99%	2.94%	5.56%	4.48%
8	2.70%	6.58%	1.49%	4.17%	10.45%	4.41%	2.78%	4.48%
9	1.35%	3.95%	0.00%	6.94%	0.00%	5.88%	4.17%	2.99%
10	1.35%	3.95%	2.99%	**9.72%**	11.94%	**11.76%**	12.50%	**11.94%**
11	8.11%	7.89%	5.97%	5.56%	1.49%	1.47%	0.00%	0.00%
12	0.00%	1.32%	2.99%	4.17%	0.00%	4.41%	12.50%	5.97%
13	9.46%	10.53%	4.48%	6.94%	7.46%	5.88%	9.72%	8.96%
14	8.11%	5.26%	7.46%	8.33%	1.49%	1.47%	0.00%	4.48%
15	1.35%	3.95%	7.46%	5.56%	1.49%	2.94%	**13.89%**	1.49%
16	**16.22%**	7.89%	11.94%	**9.72%**	2.99%	7.35%	0.00%	5.97%
17	0.00%	0.00%	0.00%	1.39%	**17.91%**	2.94%	9.72%	7.46%
18	0.00%	0.00%	4.48%	5.56%	1.49%	2.94%	2.78%	8.96%
19	5.41%	1.32%	2.99%	1.39%	5.97%	4.41%	0.00%	7.46%
20	5.41%	2.63%	8.96%	**9.72%**	2.99%	2.94%	0.00%	7.46%

Green: Photograph 16 matches Skull A, and photograph 10 Skull B.

Grey: False positive matches that had identification rates equal to or higher than true positive matches.

During the second identification session, 30 other independent observers were asked to compare a photograph of the actual individual with only the four reconstructions from the skull of that individual, and then identify the most *alike* reconstruction. Details of the procedure are given in Chapter 3 (Materials and methods). When a reconstruction was chosen as a match to a photograph, it scored one point (Appendix F). *Likeness rates* were calculated for each reconstruction by dividing the score for each reconstruction at a photograph by the total score for all the reconstructions of that photograph. For example, Skull A (the reconstruction with values from the current study) was chosen as a match to the photograph of Individual 1 a total of 17 times. The remaining 3 reconstructions altogether were chosen as a match to that same photograph 13 times, therefore the total number of matches that were made to the photograph of Individual 1 is 30. Thus, the likeness rate of the reconstruction from this study is 17 out of 30 (56.7%). This was calculated for all four reconstructions for each of the two photographs. The likeness rates are shown in Table 4.7.

For both Individuals 1 and 2, the reconstructions created from the STT values from the current study scored likeness rates higher than the other reconstructions. For Individual 1/Skull A, the reconstruction from values from the current study scored a likeness rate of 56.7%, more than twice the second highest rate of 23.3% for the reconstruction using STT values from Manhein *et al.* (2000). Here the reconstruction from Rhine and Campbell (1980) data (20.0%) also fared better than that of Phillips and Smuts (1996) data (0.0%), thus the three reconstructions based on data from black female faces fared better than the reconstruction based on coloured female data.

For Individual 2/Skull B, the likeness rates for the reconstruction from STT values of the current study scored the highest likeness rate of 43.3%. Although not as high as for Individual 1, it is still much higher than the second highest rate of 26.7% for the reconstruction using values from Manhein *et al.* (2000). Rhine and Campbell (1980) scored likeness rates of 20.0% and Phillips and Smuts (1996) 10.0%.

Table 4.7 also includes results of the Pearson's Chi-squared test. In the case of Skull A/Individual 1, the reconstruction using STT values from the current study was selected statistically significantly more often ($p<0.05$) than any of the others, but this was not the case for Skull B/Individual 2 ($p<0.05$).

Table 4.6 Summary of the identification rates for the true positive photographs at each reconstruction (first identification session), and Chi-squared (X^2) values indicating whether the identification rates are above chance

	Database for STT values used on reconstruction	Identification rate (%)	Chi-squared value
Skull A / Individual 1	Current Study	16.22 %	104.43
	Manhein *et al.* (2000)	7.89 %	39.26
	Phillips and Smuts (1996)	11.94 %	41.96
	Rhine and Campbell (1980)	9.72 %	23.00
Skull B / Individual 2	Current Study	11.94 %	53.90
	Manhein *et al.* (2000)	11.76 %	24.94
	Phillips and Smuts (1996)	12.50 %	58.56
	Rhine and Campbell (1980)	11.94 %	33.60

Green: Identification rate above chance (Expected identification rate = 5%. Universal value for the X^2 factor = 30.14, for $p < 0.05$ at $df = 19$)

Table 4.7 Likeness rates of the reconstructions when compared to the photographs (second identification session) and Chi-squared (X^2) values indicating whether the likeness rates are above chance

	Scores counted (Likeness rate (%))	
Database for STT values used on reconstruction	**Skull/Individual A**	**Skull/Individual B**
Current Study	17 (56.67%)	13 (43.33%)
Manhein *et al.* (2000)	7 (23.33%)	8 (26.67%)
Phillips and Smuts (1996)	0 (0.00%)	3 (10.00%)
Rhine and Campbell (1980)	6 (20.00%)	6 (20.00%)
Chi-squared value	19.87	7.07

Green: Identification rate above chance (Expected identification rate = 25%. Universal value for the X^2 factor = 7.82, for $p < 0.05$ at $df = 3$)

CHAPTER 5 – DISCUSSION

5.1 INTRODUCTION

The purpose of this study was twofold. Firstly, a soft tissue thickness (STT) database for South African black females was developed in order to add the data to existing literature on STT values for the purpose of forensic facial reconstruction (FFR). This was carried out by measuring the soft tissues on computerised tomography (CT) scans of 154 patients already on file. Predetermined landmarks were identified and measured on horizontal CT scans and lateral topograms. The average of the measurements at each landmark was calculated as the average STT at that landmark.

The second purpose of the study was to test the accuracy and recognisability of faces after being reconstructed with the newly developed standards. For this the Manchester method of facial reconstruction was employed to build the faces on two skulls that were made available from the Forensic Science Laboratory (FSL). These skulls were from actual cases of which victims that were positively identified and photographs were available. Four casts were made of each skull, and four different STT databases for black females, including the newly developed values from the current study, were used as the STT for the reconstructions of the faces. The four different outcomes could be compared to each other. In order to assess whether population-specific STT values actually make a difference, identification sessions were held. In the first identification session, assessors or observers had to identify the true photographs that matched the skulls out of a group of 20 photographs of black females between 18 and 30 years of age. In the second identification session, different assessors were asked to match the actual photograph of the individual to one of the four reconstructions of the same skull.

The outcomes of the results, the significance of the differences between the databases used and the accuracy or identification rates of the different reconstructions will be discussed, and an indication given on how it can be used in practice. This chapter will also focus on the sample size and how it compares with similar studies conducted in the past, as well as drawbacks and problems experienced during the study.

5.2 DISCUSSION OF RESULTS

5.2.1 Tissue Thickness Measurements

The data presented in this study are a set of average facial soft tissue depth measurements to contribute to a more accurate reproduction of a face on a skull. This data is for specific application to the skull of black females, specifically of South African origin, as a guide to the depth of the soft tissues overlying the skull. This data was taken from CT scans of living subjects.

The landmarks that showed the smallest values include A – Supra-glabella, N – Frontal eminence and O – Fronto-temporale, which all fall on areas on the forehead, and D – End of nasals and E – Lateral nasal, which fall on the nose. These are the areas that, when palpating a living individual's face, appear to be the thinnest areas, or where the skin is the closest to the bone. These are also the areas where the least changes are observed during body weight changes due to the small amount of subcutaneous fatty tissue. The range, being the difference between the maximum and minimum, is related to the change in body composition and weight, and therefore could furthermore reflect the extent that body weight will influence the tissue thickness at a specific landmark. The landmarks that show the smallest ranges are A – Supra-glabella, D – End of nasals, E – Lateral nasal, N – Frontal eminence, O – Fronto-temporale, P – Supra-orbital and M – Beneath chin. The small average measurement and range at landmark M may make sense if one considers that this measurement was taken at the most anterior (forward) point on the inferior (lower) border of the mental eminence of the mandible. When a live individual's face is palpated at this landmark, it is felt that at this point the skin is close to bone, and the thicker chin (double chin) seen in more obese or older people, only starts a little more posteriorly (backward), towards the neck, and not immediately at the border of the mandible, therefore the range for this specific point where the measurements were taken is not large.

The largest values, with thickest skin folds, were measured on the landmarks R – Zygomaxillare, U – Area of the parotid, V – Mid-masseteric, W – Gonion, X – Supra M^2, Y – Sub M_2 and Z – Occlusal line. These areas also show the widest ranges. If the range is larger, it can be assumed that the area is easily influenced by body build. These are all landmarks that fall on the maxilla or mandible, therefore the areas around the mouth and cheeks. It is not surprising that these areas have the largest tissue thickness depths, since it is commonly known that when facial changes occur due to weight gain, the areas mostly affected, or where the changes are most clearly seen, tend to be around the cheeks. This is most likely due to the fat pads and other large amounts of fatty tissues found around the cheeks. The wide ranges reflect the influence that the different body builds can have on the results of STT measurements and show how tissues in the face can change along with a change in body weight and gain or loss of facial fat. This high variability of the measurements also reflects inter-individual variation. With practical application to reconstructions, these areas enhance the importance of using population-specific data for facial reconstructions, in this case, values from the current study for reconstruction on South African black female skulls.

When compared to other databases (Table 4.2), some landmarks show a significant difference between the tissue thickness measurements. A total of nine landmarks show a significant difference with data from Manhein *et al.* (2000) ($p \leq 0.01$), four with Phillips and Smuts (1996) at $p \leq 0.01$ and three at $p \leq 0.05$, and 17 with Rhine and Campbell (1980) ($p \leq 0.01$).

Compared to measurements from Manhein *et al.* (2000), the landmarks showing significant differences with $p \leq 0.01$ are B – Glabella, D – End of nasals, H – Mid-philtrum, II – Upper incisor, P – Supra-orbital, Q – Sub-orbital, S – Lateral zygomatic arch, T - Supra-glenoid and X – Supra M^2. Compared to measurements from Phillips and Smuts (1996), the landmarks showing significant differences with $p \leq 0.01$ are H – Mid-philtrum, T – Supra-glenoid, X – Supra M^2, and Y – Sub M_2**.** C – Nasion, P – Supra-orbital, and W – Gonion show a significant difference with $p \leq 0.05$. Compared to measurements from Rhine and Campbell (1980), the landmarks showing significant differences with $p \leq 0.01$ are B – Glabella, C – Nasion, D – End of nasals, H – Mid-philtrum, I – Mid upper lip margin, L – Mental eminence, M – Beneath chin, N – Frontal eminence, P – Supra-orbital, Q – Sub-orbital, R – Zygomaxillare, S – Lateral zygomatic arch, T – Supra-glenoid, W – Gonion, X – Supra M^2, Y – Sub M_2 and Z – Occlusal line.

Some of these differences may be attributed to difference in positioning (Vandermeulen *et al.* 2006) of the subjects on which the measurements were taken, in other words the upright position for ultrasound-based measurements (Manhein *et al.* 2000; Vandermeulen *et al.* 2006), or supine for CT scans (Phillips and Smuts 1996; Vandermeulen *et al.* 2006) and cadaver-based measurements (Rhine and Campbell 1980). The reason why less statistical significant differences are seen between the measurements of South African black females (from the current study) and South African (Cape) Coloureds (from Phillips and Smuts (1996)) could be due to genetic admixture between population groups over generations within the country's borders (genetic similarities between the two samples, and both are from the same subcontinent). These significant differences show that population groups differ with STT distributions on the face, and further enhance the importance of using population-specific data, but again the effect can only be indicated by practical application.

5.2.2 Reconstructions and identification sessions

Eight reconstructions were created for practical evaluation of the tissue thicknesses from four different databases. As expected, the landmarks with significantly different values resulted in clear differences in the facial shapes of the reconstructions.

Since the purpose of these reconstructions was to evaluate the effect of different tissue thicknesses on the same skull, other features that could have an influence on the appearance of the face had to be kept constant. These features include the shape of the eyes, eyebrows, nose, ears and hair. Therefore, the reconstructor attempted to sculpt these features to a shape as close as possible to each other according to the protocols as described by Wilkinson (2000). Although the shape of the mouth and lips also have a great influence on the appearance of the face, the many measurements that are related to landmarks on and around the teeth prevented the reconstructor from keeping these shapes absolutely the same.

Figures 4.29 to 4.31 show the reconstructions that were created on Skull A and were compared to Individual 1. In Figures 4.29 to 4.31 it can be seen that the differences in the outcomes of the facial shape in the reconstructions for Individual 1 are quite obvious. The significant differences in the tissue thickness values on the cheeks and jaw, especially at landmarks X – Supra M^2 and Y – Sub M_2, are clearly reflected. Viewed from the front, all four reconstructions resulted in a face with a fairly natural and relaxed appearance. But when viewed from the side (lateral profile) and three-quarter angles, the reconstruction from Phillips and Smuts (1996) reveals a face with the mouth in a pouted expression and hollow cheeks. This pouting appearance is less desirable on reconstructions, since one wants the expression of a reconstruction to appear as natural as possible to prevent these expressions from decreasing the recognisability of the face.

In comparing the reconstructions with the actual photograph of Individual 1, the overall round and broad face shape of the individual is well reflected in the reconstructions based on tissue thicknesses from the current study (Figure 4.29i), Phillips and Smuts (1996)

(Figure 4.29ii) and Rhine and Campbell (1980) (Figure 4.29iii). The tissue thicknesses from Manhein *et al.* (2000) brought about a reconstruction with a too narrow facial shape. Also, when viewing the superimposed outlines of the reconstructions (Figure 4.36), the narrower shape of the reconstruction from the Manhein *et al.* (2000) values is clearly seen. With all the reconstructions, the forehead shape correlates well, and the eyes and nose shape (although not a specific feature of interest) match fairly well with the photograph of the actual individual. The mouth is too wide and lips too thin for all four reconstructions.

It is unfortunate that only one photograph of the actual individual was available, since comparisons from the lateral and three quarter profiles may also have brought other favourable or unfavourable comparisons to light.

Figures 4.32 to 4.34 show the major differences in the outcomes of the reconstructions based on the different databases for Skull B. In Figures 4.32 to 4.34 the significant differences in the tissue thickness values on cheeks and jaw are again clearly reflected. With all four reconstructions, the forehead and areas around the eyes have a fairly good resemblance to the actual individual, but the maxillary and mandibular areas show some differences. The reconstructions have produced noses that were not quite accurate, except for the nostrils flaring upward, and the lips seem to be too wide. The reconstructions based on results of the current study (Figure 4.32i) and on the Manhein *et al.* (2000) values (Figure 4.32ii) have produced strong and broad jaw lines, whereas that of Phillips and Smuts (1996) (Figure 4.32iii) and Rhine and Campbell (1980) (Figure 4.32iv) produced more triangular to oval jaws. On the lateral profile the reconstructions produced a prognatic face, as expected on the South African black population groups, except for the Manhein *et al.* (2000) data (Fig 4.33ii) which produced a rather flattened face. A flatter face does not follow the natural trend of facial profile appearance for black female faces. It is difficult to compare the frontal or lateral views of the reconstructions with the actual individual though, since the photograph was taken from a three-quarter angle.

When the three-quarter profile angles of the reconstructions are compared, the reconstructions from Phillips and Smuts (1996) (Figure 4.34iii) and Rhine and Campbell (1980) (Figure 4.34iv) reveal a face with the mouth in a pouted expression. Again this pouting expression is less desirable since the ideal is a face as relaxed and natural as possible. In comparing the reconstructions with the actual photographs of Individual 2, the slope of the cheeks are better resembled on the reconstructions based on data from the current study and Manhein *et al.* (2000) rather than the sunken-in cheeks from Phillips and Smuts (1996) and Rhine and Campbell (1980). None of the reconstructions revealed the dimple in the chin of the actual individual.

When viewing the superimposed outlines of the reconstructions (Figure 4.37), none of the reconstructions show any features that stand out more significantly than the rest, although the broader jaw line from the current study is clearly seen from the frontal view, and the sunken in cheeks and chin from Rhine and Campbell (1980) is seen in the three quarter view. The fact that none of the reconstructions really show features that significantly stand out more than any other, could indicate that the reconstructions from STT of the current study represents a good normal face possible for that skull, that is, a good average between the different STT values that is available.

Again it is unfortunate that only one photograph of the actual individual was available, since comparisons from the front and lateral profiles may also have brought other favourable or unfavourable comparisons to light.

During the identification sessions, the independent observers that participated had a chance to compare the photograph of the actual individual with the 3D reconstruction, as well as the photographs of the reconstructions. Viewing the 3D reconstructions gave them a better perception of the overall outcome of each reconstruction, but still only the photograph of the actual individual from one angle was available for comparison. In the first identification session, wherein the actual individual's photograph was part of a random group of photographs from individuals of the same age, observers had to identify the photograph that best matched the reconstruction.

Prior to the identification sessions, the observers were briefed on the procedure and the purpose of the study and the identification sessions, as well as the development of the tissue thickness values and reconstructions. Even though it was stressed that the effect of the tissue thicknesses on the overall facial shape of reconstruction is what was tested, whether the observer's choices for the best match to a photograph was made upon comparing face shapes, proportions or individual features, could not be controlled. This could have a large effect on the outcome of the identification rates and randomness of the results.

In an overview (Table 4.6) of all the photographs and reconstructions for Individual 1, it is clear that population-specific tissue thicknesses had a large influence on the identification or recognisability of the face. Both the reconstructions that resulted in the highest identification rates for the actual photographs were from South African values (either from the current study, or from Phillips and Smuts (1996) data), which could indicate that both these sets of tissue thicknesses have resulted in a facial shape trend that is more common to South African faces than the two sets of American values.

In view of the identification rates scored by the false positive photographs at Skull A/Individual 1, individuals 1, 3, 6, 10, 11, 13 and 20 seem to have been similar in appearance to the actual individual, but it is unclear on which features these similarities were based. It is also unfortunate that ethical clearance has not been granted to publish the photographs of the random individuals to indicate or discuss the similarities or differences between the actual photograph and that of the random individuals for a better understanding of the results.

During the second identification session, a new group of observers had to match the four reconstructions from the same skull to the relevant photograph of the actual individual, and then choose the reconstruction that had the best resemblance. Again, for Skull A, the reconstruction with South African-based tissue thickness values from the current study fared much better than the other data sets (Table 4.7). This further strongly supports the idea of using population-specific data.

Viewing the results for Individual 2 during the first identification session, all four sets of data produced identification rates close to each other for the reconstructions. Both reconstructions based on South African data scored the second highest identification rates. During the second identification session, Skull B/Individual 2's reconstruction, based on data from the current study, again produced the highest likeness rates. Although not as high as for Individual 1, it was still much higher than the likeness rates for the reconstructions based on Manhein *et al.* (2000), Rhine and Campbell (1980) and Phillips and Smuts (1996).

This produces further support towards the use of population-specific data, if available, in reconstructions to increase the chance of recognition. It seems that this population-specific data produces a reconstruction that has a stronger resemblance to faces of the same population, and has a greater appeal to the people that have to recognise it, but not using population-specific data would not decrease resemblance so much as to completely prevent recognition or even just a spark towards recognition. In the current study, the use of the newly developed STT values produced a more natural appearance on the reconstructions, and the true individuals (which were from the same ancestry as the individuals from which the STT values were measured) were identified fairly often.

For Individual B the results had a completely different "trend" than Individual A. This might indicate that population-specific STT values may be necessary (the use thereof significant), but the true affect thereof will vary with each skull and reconstruction. For both individuals, the reconstructions with Phillips and Smuts (1996) values were selected the least. This supports the use of race-specific STT values, since Phillips and Smuts (1996) data were based on a mixed origin population group, whereas the other three databases used were from black population groups.

5.3 REPEATABILITY

The intra- and inter-observer repeatability tests were done after the initial measurement of all the CT scans in the sample population. The CT scans for inter- and intra-repeatability were chosen at random. The CT scan program used for measuring the scans does not allow one to save any measurements done on that scan, therefore no measurements could possibly be remembered. The CT scans were re-measured by an MSc student.

In order to assure high repeatability of the location of the landmarks for measurement, these landmarks were well described and, where possible, narrowed to an exact point that would be similar to all CT scans each time. However, some chosen landmarks have been that of areas where the exact point of location could only be estimated.

The intra-observer repeatability was calculated using the intra class correlation. The results are shown in Table 4.3 where it is seen that most of the measurements were repeatable. Measurements that did not correlate well between the first and second measurements, were that of the mid lower lip margin, frontal eminence, glabella, mid-philtrum and zygomaxillare. This could have been due to a difference in interpretation of where the exact location of the landmarks are found, especially with the mid-philtrum and zygomaxillare, or due to the difficulty and difference in estimating the landmarks where it is not an exact point such as the glabella (not a prominent point in females), and the frontal eminence. This could also have been the reason for the lower repeatability values for the lateral supra-labiale, gonion and supra-glenoid landmarks. Concerning the gonion, the masseter muscle has a strong attachment on the angle of the mandible, leaving a bone print in the form of vertical crests (Tilotta *et al.* 2009). This has an impact on the morphology of the mandibular angle, where the gonion landmark is situated, by sometimes laterally deforming the bone rim (Tilotta *et al.* 2009). The degree of this lateral deformation can not always be determined and this bone curvature added to the difficulty in measuring a reliable value at this landmark (Tilotta *et al.* 2009).

The inter-observer reliabilities were relatively high, with the highest including that of the sub-orbital, lateral zygomatic arch, mid-masseteric and occlusal line measurements, and the most unreliable appearing to be the measurements for the lateral supra-labiale and mid-philtrum landmarks. This may have been due to a difference of estimating the position of the landmarks between the two observers. Although the descriptions of the landmarks were clear, interpretation of these descriptions at some of these landmarks could have been varied.

In general, there is little correlation between the variables that were difficult to repeat between the original observer (intra-observer) and the second observer (inter-observer). This may be explained due to small differences in how the observer(s) uses the measurement device, the fact that the sample measured by the two observers was not exactly the same, and it is possible that a few more ambiguous cases were included in the sample of the original observer.

Another factor that could have influenced the results is the estimation of the border of the bone or skin surface. Due to some CT scans' distortion or pixilation when zoomed in, the positions of the surfaces may have been slightly over or under estimated at times. By keeping the position of the measurement endpoints similar, that is, from the outer border of the skull to the outer line of the border of the skin, these differences should have been eliminated. The Cobb angle (described in Chapter 3) ensured that all the measurements were done as close as possible to 90˚ from the bone surface, therefore the angle of the measurement line should not have influenced the STT measurement.

The effect of the difference in the values of the measurements from the original and second observers is still unclear. However, since these differences are not more than 1 mm for any of the landmarks, the difference that it will make on the appearance of a reconstruction is not expected to be much.

Overall, even though the measurements that were not repeatable were mostly focussed on, the majority of the measurements did show high repeatability and support the use of CT scans for tissue thickness measurement, as well as the reliability and accuracy of the data. It was found that the most reliable measurements consisted of landmarks which had a clear and to-the-point description, enhancing the importance for the investigator of choosing well-described landmarks and features that can be easily repeated by others. This is also relevant when choosing the landmarks for facial reconstructions. The position of the tissue pegs should be clearly described, and will be easier to repeat for landmarks that fall on an exact point, rather than estimation on a larger area.

The repeatability of the reconstructions was not tested, since this will be an investigation on its own, and it was not part of the aim of the current study. Facial reconstruction is a subjective method that will depend greatly on the techniques and experiences of the artists. Investigation of the outcome if the same skull is reconstructed by two different artists, regardless of whether the same tissue thickness database is used, could be attempted in future studies.

5.4 COMPARISON WITH OTHER STUDIES

5.4.1 Sample size

This study employed a large sample of 154 individuals, aged between 18 and 35 years. Due to the nature of the CT scans, the sample size at each landmark is different, depending on the visibility of the landmarks for measurement on the scans. This varying sample size for the landmarks can be seen in Chapter 4 (Results), Table 4.1. Even with regard to the landmark with the smallest sample size for the current study (n=17), this is the largest sample size of a group of South African female faces used in a research study. Other studies that measured South African faces were that of Aulsebrook *et al.* (1996) who used 55 black males (aged 20 to 35 years), and Phillips and Smuts (1996) who included 16 males and 16 females of a mixed race population group (aged 12 to 71 years) for their measurements. Other studies that measured American Negroid female faces had study populations of 15 females (average age of 32.8 years) (Rhine and Campbell 1980) or 44 adult females of which 18 were between 19 and 34 years of age (Manhein *et al.* 2000).

With comparison to international studies, the sample size of the current study, as well as the number of landmarks used, is one of the largest to date, and thus may better reflect the possible variation of facial tissues. The large number of landmarks used in the current study (12 midline and 16 bilateral measurements) may have been useful to provide a better guide towards the facial shape and contours. Other relatively large sample sizes such as this have been used in the research by Manhein *et al.* (2000), who measured 19 points across the face of a total of 256 adults, further subdivided into males and females, black and white, and further grouped in various age groups, in their study. Sahni *et al.* (2008) used 173 male and 127 female adult subjects of northwest Indian origin to determine facial STT at 29 anthropological landmarks. De Greef *et al.* (2006) had one of the largest sample sizes, consisting of 510 Caucasoid women and 457 Caucasoid men who participated in their study to measure 52 landmarks across the face.

Although this study included a large sample, it is by no means a clear representation of the whole South African black female population, since people in the Southern parts may, for example, be different. Therefore, more research is recommended, perhaps with more background on the subjects, to also assess the effects of, for example, age and body mass index (BMI) on STT values.

5.4.2 Similar protocols

Many studies have been conducted on measuring and publishing STT values for specific population groups, and statistically comparing these values with other previously established databases of similar population groups. However, only a few studies (discussed in Chapter 3, section 3.2.4 (Comparison to other studies)) involved practically testing these measurements on reconstructions and comparing them to photographs to determine the accuracy and influence of these measurements on reconstructions and recognition. The current study attempted to determine this influence. More studies like this should be useful, wherein multiple reconstructions are utilised to test the effect that the range of human variation has on the recognition of reconstructions and identification of individuals in forensic investigations, so that recognition and identification can be improved towards higher success rates.

5.5 DRAWBACKS AND PROBLEMS EXPERIENCED

5.5.1 Problems of sampling

In order to measure STT values that resemble that of a whole population, a substantial number of CT scans was needed. Since this study was conducted in the northern part of the country, we can presume that it reflects, for example, the Gauteng area's population groups, but less well other population groups elsewhere in South Africa. Also, the ideal would have been to use CT scans of individuals of which the age, ancestry, exact health status and BMI were known. Unfortunately, recruiting volunteers to be scanned is an ethical problem due to unnecessary exposure to radiation, albeit small. Therefore, CT scans had to be used from patients already on file. The shortcoming of this is that the BMI of these individuals could not be obtained, therefore the CT scans could not be categorised according to BMI and this prevented the study from measuring average STT's for different classes of body builds. The average STT's shown in this study is that of the whole range of possible body composition of the population group.

5.5.2 Identification of landmarks

The landmarks and measurements chosen for this study were previously used by researchers such as Aulsebrook *et al.* (1996), Phillips and Smuts (1996), Manhein *et al.* (2000) and Wilkinson (2004). The various definitions for the landmarks were combined to produce a set of points for acquiring depth measurements on CT scans. Although careful consideration was given to choosing the landmarks and measurements, there was still some difficulty with the identification or location of some of the landmarks on the CT scans. All the CT scans were not taken on the same levels, therefore all the landmarks did not fall on the same level for each patient. The grid overlaid on the topogram was used to determine on which level of CT scan slices a landmark should fall, but many times the exact level had to be estimated. Also, since the axial slices on a CT scan are a few millimetres from each other, many of the landmarks which were an exact point were not shown on the slices, due to them falling on a level between two successive slices (Nelson and Michael 1998).

Files of patients that were sent for brain scans were most frequently used, since an anomaly in the brain should not have an effect on the facial appearance or underlying soft tissues. Whenever an alteration of the facial tissues was suspected, the patient was excluded for the soft tissue measurements. Using mostly brain scans also had some drawbacks. Most of the brain CT scans used in this study included only the region of the scalp to the maxilla. The mandible was mostly not visible to be measured. This resulted in a much smaller sample size for measurements on the mandible and around the maxillary teeth. Sometimes a CT scan was extended to the lower head region, or a patient was also sent for a cervical spine scan, giving results on the mandibular area. In some patients that were sent for CT scans of the head region, the indication for scanning was frequently a facial fracture or tumour, which had to be excluded due to alterations that these have on the facial soft tissue composition.

A further problem was encountered as not all CT scans were taken exactly parallel to the Frankfurt Horizontal plane, thus it was not possible to control the measurement angle to the bone in multiple planes (Nelson and Michael 1998). Although one can measure the STT perpendicular to the surface contours of the bones in the horizontal axis, one cannot be sure that it is measured perpendicularly to the vertical axis. No compensation could have been made for this on the type of CT scans available for this study, since all the scans were of horizontal slices, except for one midline topogram. This error is further amplified, since the angle of the markers placed on the skull is also not defined and may significantly alter the resulting reconstruction (Nelson and Michael 1998). To test the influence of this or to correct the values for the STT's, 3D spiral CT scans or perhaps ultrasound could be used. Although CT scans seem to have many pitfalls, it has remained a method of choice for many researchers and the investigator had to rely on the reported positive feedback of using CT scans for measuring STT's (Phillips and Smuts 1996; Kim *et al.* 2005; Turner *et al.* 2006; Vandermeulen *et al.* 2006; Tilotta *et al.* 2009). The equipment is not complex to use, the majority of the tissue thicknesses is highly visible and the potential does exist to collect a large number of tissue thickness measurements using well defined landmarks and having good contrast between the soft tissues and bone (Nelson and Michael 1998). A major advantage of using CT scans rather than, for example, ultrasound is that the images can be saved for future reference, which makes it easier to re-measure for tests of repeatability or to increase sample sizes in other similar studies.

5.5.3 Obtaining photographs for the identification sessions

Assessing the accuracy of reconstructions is not always possible, since matching photographs are not always available. In this regard, a unique opportunity arose where two skulls were positively identified and photographs of the individuals were available. Permission was granted to the researcher to use these photographs, since the use of these photographs would contribute to a research investigation which could be of benefit to the FSL. These photographs should be preserved for future use and, should more cases like these arise, included in larger, similar studies.

Permission to use photographs of other individuals to create a wider range of photographs from which to choose during the identification sessions was more problematic. The research ethics committee granted this permission on the condition that none of the photographs of the random individuals are published. The photographs were recruited from black female students, in the same age range as the deceased individuals. The students were briefed on the purpose of the study, their photographs and the identification session. Consent forms were handed to the students with a written description of the study and the purpose thereof, as well as their photographs and the identification session (Appendix C). The students had the choice not to participate. If they did choose to take part, they only had to hand in a recent portrait photograph of themselves, which was scanned and then given back to the students. Many students, however, did not choose to take part. The reason for many of them was that they are shy of photographs of themselves and do not want anyone to see them, even though it was explained that these would only be shown to the observers for a scientific study, and to no-one else. Also, all the photographs had to be modified to a quality similar to the quality of the two photographs of the deceased individuals to assure that no unfair hint was indicated towards any of the two matching photographs in the identification sessions. For this reason, printed photographs were preferred above digital photos, so that they could be scanned, similar to those of the two deceased individuals.

Furthermore, most of the photographs that were handed in by the students were passport-type photographs. The disadvantage of this was that these photographs may suggest that they were purposefully added to the series, or they may cause the non-passport type photographs to stand out more than the rest. To reduce these effects, the investigator attempted to standardise the photographs in terms of lighting, resolution and background, and all the photographs were displayed in greyscale for the identification sessions. This may have helped to reduce bias for choosing which photograph best matched the reconstruction, since many of the false positive photographs that were eventually chosen by observers were of the passport-type photographs.

5.6 HOW TO USE THE RESULTS OF THIS STUDY

The results obtained in the current study represent the facial tissue thicknesses for a black female population group of South Africa for facial reconstruction purposes. No other similar study has been conducted in South Africa in which the soft tissues of the faces of South African black females have been measured (Phillips and Smuts 1996).

Facial reconstruction from the skull can be a complex task, since there is a wide variety in human faces, and although the skull gives much detail on the overlying features, it will never give a hundred percent accurate estimation of what the features should actually look like. STT measurements are used as guidelines to the depth of the tissues overlying specific landmarks. These tissue thickness measurements are believed to vary according to specific ancestries, ages and sexes. This study established population-specific tissue thickness values for South African black females, therefore these data are for use on a skull of an individual from this same population group. This is the length that the various tissue thickness pegs should be cut, for application onto skulls prior to reconstruction. It should be kept in mind that these values, that is, the mean of the measurements at each landmark (Table 4.1), are calculated to the nearest 0.1 mm. However, in practice, to cut to such a length is almost impossible and other investigators have suggested rounding the value for cutting the pegs to a more practical measurement. This choice of where it can be rounded is up to the reconstructor. The data published by Rhine and Campbell (1980) were read off a metric scale to the nearest 0.25 mm, and Aulsebrook *et al.* (1996) have stated that when it comes to the practical stages of reconstruction, the figures may be rounded to the nearest 0.5 mm. Using appropriate tissue thickness data will undoubtedly add credibility to any facial reconstruction. However, these tissue pegs should only serve as a guide to the facial shape and contours, and the reconstructor should refrain from blindly accepting this data in the light of informed analysis of the skull's idiosyncrasies (Rhine and Campbell 1980). It must also be remembered that these measurements were done on a wide variety of body builds and thus the values are mean measurements that represent the average face. Since average values are used, these STT measurements may underestimate the true facial dimension on some individuals, and overestimate on others (Rhine and Campbell 1980). To prevent this, the reconstructor must consider any information on the specifications of the individual, such as clothing size, and may adapt the thickness of the pegs accordingly, that is, to either the minimum or maximum values. The face shape and features can be adapted if the skull of a thinner or obese person is reconstructed, but further investigation is still needed to establish specific tissue thicknesses for thinner or more obese people. The standard deviation of the mean may serve as a good guide as to how much of the tissue thickness could be subtracted or added to the tissue thickness value if a thinner or more obese face is to be reconstructed. In general, the sculptor must be encouraged to utilise all the anthropological information available from the close examination of the skull, but to be cautious in striving so enthusiastically for realism that he/she produces a distorted version of the subject (Rogers 1987).

CHAPTER 6 – CONCLUSION

- This study produced STT values of South African black females, using 154 individuals. These values should be used in future reconstructions of female skulls, specifically from the black South African population. Repeatability of the measurements was generally good.

- FFR remains a difficult subject to assess scientifically but it can be rectified if a standard for accuracy assessment could be decided on. Having antemortem photographs for specific skulls could be useful for resemblance or likeness ratings, but accuracy assessment should rather be conducted by face pool identification sessions or face array tests, with larger groups of observers. Skulls with matching photographs are rare commodities and should be preserved for future use. If more can be added, sample sizes can be increased for further analysis of the accuracy of reconstructions, and consequently the STT measurements.

- Population-specific STT values are important, as skulls reconstructed using these values were selected/identified above chance.

- Facial reconstruction from a skull is a challenging but interesting aspect of forensic investigation. Although it has pitfalls in its application, identification sessions indicated that, on the whole, FFR is a valid method to use, as the correct individuals were chosen often. However, the levels of accuracy are not high enough to be used for purposes of personal identification.

- Collecting more information, such as background knowledge on FFR, education, age, sex, ethnicity and so forth, of assessors or observers that participate in face array tests or identification sessions may also be useful for investigating the results of the assessment of facial reconstructions.

- Future studies should utilise larger sample sizes and as much information as possible, such as BMI, age, health status, ethnicity and perhaps even family history, of the sample group to be measured. The STT values should then be subdivided into specific groups, should there be cases that this specific information is required. However, these subgroups should also be grouped together to provide the STT values in a simplified yet statistically stronger database. This may especially be helpful when a skull, of which the exact subgroup or similar clues are unknown, needs to be reconstructed.

- Establishing standard methods for STT measurement and limiting FFR to specific methods of facial feature determination and creation on a skull, should help to eliminate subjectivity of the practice, however, the subjective influence of the artist or sculptor and also the subjective observation of assessors are, in the end, inevitable.

- It is still unclear whether facial recognition is dependent on proportions of, or the exact shape of the independent features sculpted on a face, since people tend to look at faces differently and rely on different features or parts of the face as recognition cues. Therefore FFR artists should focus on all these aspects while creating a reconstruction and further investigation into how faces are recognized by different individuals could be helpful.

REFERENCE LIST

Allan J.C. 1982. *Learning About Statistics.* Macmillian South Africa (Publishers) PTY.LTD.

Aulsebrook W.A., İşcan Y.M., Slabbert J.H. & Becker P.J. 1995. Superimposition and reconstruction in forensic facial identification: a survey. *Forensic Science International* 75: 101–120.

Aulsebrook W.A., Becker P.J. & İşcan Y.M. 1996. Facial soft-tissue thicknesses in the adult male Zulu. *Forensic Science International* 79: 83–102.

Aulsebrook W.A. 2000. Facial tissue thickness in facial reconstruction. In: Siegel J.A., Saukko P.J. and Knupfer G.C. (eds) *Encyclopaedia of Forensic Sciences*. Vol. 2. Academic Press. pp 779–788.

Bronstein A.M., Bronstein M.M. & Kimmel R. 2005. Three-dimensional face recognition. *International Journal of Computer Vision* 64(1): 5–30.

Brown R.E., Kelliher T.P., Tu P.H., Turner W.D., Taister M.A. & Miller K.W.P. 2004. A survey of tissue-depth landmarks for facial approximation. *Forensic Science Communications* 6(1): 1–27.

Burns K.R. 2007. *Forensic Anthropology Training Manual*. 2nd ed. Pearson Education LTD. pp 225–230.

Claes P., Vandermeulen D., De Greef S., Willems G. & Suetens P. 2006. Craniofacial reconstruction using a combined statistical model of face shape and soft tissue depths: Methodology and validation. *Forensic Science International* 159S: S147–S158.

Codinha S. 2009. Facial soft tissue thickness for the Portuguese adult population. *Forensic Science International* 184(80):1–7.

Conant E. 2003. Man of 1000 Faces: The forensic genius of Mikhail Gerasimov. *Archaeology Magazine* 56(4): 48–49.

DeCarlo D., Metaxas D. & Stone M. 1998. An anthropometric face model using variational techniques. *Proceedings SIGGRAPH* pp 67–75.

De Greef S. & Willems G. 2005. Three-dimensional cranio-facial reconstruction in forensic identification: Latest progress and new tendencies in the 21st century. *Journal of Forensic Science* 50(1): 1–6.

De Greef S., Claes, P., Vandermeulen D., Mollemans W., Suetens P. & Willems G. 2006. Large-scale in-vivo Caucasian facial soft tissue thickness database for craniofacial reconstruction. *Forensic Science International* 159S: S126–S146.

Domaracki M. & Stephan C.N. 2006. Facial soft tissue thicknesses in Australian adult cadavers. *Journal of Forensic Science* 51(1): 5–10.

El-Mehallawi I. H. & Soliman E. M. 2001. Ultrasonic assessment of facial soft tissue thicknesses in adult Egyptians. *Forensic Science International* 117: 99–107.

Farkas L.G., Katic M.J. & Forrest C.R. 2005. International anthropometric study of facial morphology in various ethnic groups/races. *The Journal of Craniofacial Surgery* 16(4): 615–646.

Ferrante L. & Cameriere R. 2009. Statistical methods to assess the reliability of measurements in the procedures for forensic age estimation. *International Journal of Legal Medicine*123: 277–283.

Galdames I.C.S, López M.C., Matamala D.A.Z., Rojas F.J.P. & Muńoz S.R.T. 2008. Comparisons in soft-tissue thickness on the human face in fresh and embalmed corpses using needle puncture method. *International Journal of Morphology* 26(1): 165–169.

Gatliff B.P. & Snow C.C. 1979. From skull to visage. *Journal of Biocommunications* 6(2): 27–30.

Gatliff B.P. 1984. Facial sculpture on the skull for identification. *American Journal of Forensic Medicine and Pathology* 5: 327–332.

Gatliff B.P. & Taylor K.T. 2001. Three-dimensional facial reconstruction on the skull. In: *Forensic Art and Illustration*. CRC Press. pp 419–475.

George R.M. 1987. The lateral craniographic method of facial reconstruction. *Journal of Forensic Science* 32(5): 1305–1330.

Helmer R.P., Röhricht S., Peterson D. & Möhr F. 1993. Assessment of the reliability of facial reconstruction. In: İşcan M.Y. & Helmer H. (eds) *Forensic Analysis of the Skull.* New York: Wiley-Liss, Inc. pp 229–246.

İşcan M.Y. 1993. Craniofacial image analysis and reconstruction. In: İşcan M.Y. & Helmer H. (eds) *Forensic Analysis of the Skull.* New York: Wiley-Liss, Inc. pp 1–9.

İşcan M.Y. & Helmer R.P. 1993. The relationship of skull morphology to facial features. In: İşcan M.Y. & Helmer H. (eds) *Forensic Analysis of the Skull.* New York: Wiley-Liss, Inc. pp 199–213.

Kim K.D., Ruprecht A., Wang G., Lee J.B., Dawson D.V. & Vannier M.W. 2005. Accuracy of facial soft tissue thickness measurements in personal computer-based multiplanar reconstructed computed tomographic images. *Forensic Science International* 155: 28–34.

Kollman J. & Buchly W. 1898. Die Persistenz der Rassen und die Reconstruction der Physiognamie Prahistorisher Schadel. *Archiv fur anthropologie* 22: 329–359.

Krogman W.M. & İşcan M.Y. 1986. *The Human Skeleton in Forensic Medicine*. 2nd ed. Springfield, IL: Charles C. Thomas, LTD.

Lebedinskaya G.V., Balueva T.S. & Veselovskaya V.S. 1993. Principles of facial reconstruction. In: İşcan M.Y. & Helmer H. (eds) *Forensic Analysis of the Skull.* New York: Wiley-Liss, Inc. pp 183–198.

Manhein M. H., Listi G. A., Barsley R. E., Musselman R., Barrow N. E. & Ubelaker D. H. 2000. In vivo facial tissue depth measurements for children and adults. *Journal of Forensic Science* 45: 48–60.

Miyasaka S., Yoshino M., Imaizumi K. & Seta S. 1995. The computer-aided facial reconstruction system. *Forensic Science International* 74: 155–165.

Nelson L.A. & Michael S.D. 1998. The application of volume deformation to three-dimensional facial reconstruction: A comparison with previous techniques. *Forensic Science International* 94: 167–181.

Phillips V.M. & Smuts N.A. 1996. Facial Reconstruction: Utilization of computerized tomography to measure facial tissue thickness in a mixed racial population. *Forensic Science International* 83: 51–59.

Phillips V.M. 2001. Case Report - Skeletal remains identification by facial reconstruction. *Forensic Science Communications* 3(1).

Prag J. & Neave R. 1997. *Making Faces*. London: British Museum Press.

Quatrehomme G., Cotin S., Subsol G., Delingette H., Garidel Y., Grévin G., Fidrich M., Bailet P. & Ollier A. 1997. A fully three-dimensional method for facial reconstruction based on deformable models. *Journal of Forensic Science* 42(4): 649–652.

Quatrehomme G. & İşcan M.Y. 2000. Facial identification. In: Siegel J.A., Saukko P.J. and Knupfer G.C. (eds) *Encyclopaedia of Forensic Sciences*. Vol. 2. Academic Press. pp 773–778.

Rathbun T.A. 1984. Personal Identification: Facial reproductions. In: Rathbun T.A. & Buikstra J.E. (eds): *Human Identification: Case Studies in Forensic Anthropology*. Springfield, IL: Charles C. Thomas Publisher, LTD. pp 347–356.

Reichs K.J. & Craig E. 1998. Facial Approximation: Procedures and Pitfalls. In: Reichs K.J. (ed): *Forensic Osteology: Advances in the Identification of Human Remains.* 2nd ed. Springfield, IL: Charles C Thomas Publisher, LTD. pp. 491–511.

Rhine J.S. & Campbell H.R. 1980. Thickness of facial tissues in American blacks. *Journal of Forensic Science* 25(4): 847–858.

Rhine J.S., Moore C.E. & Weston J.T. (eds). 1982. Facial reproduction: Tables of facial tissue thickness of American Caucasoids in forensic anthropology. Maxwell Museum Technical Series No. 1, University of New Mexico, Albuquerque.

Rhine J.S. 1984. Facial reproduction in court. In: Rathbun T.A. & Buikstra J.E. (eds) *Human Identification, Case Studies in Forensic Anthropology*. Springfield, IL: Charles C Thomas Publisher, LTD. pp 357–362.

Rhine J.S. 1990. Coming to terms with facial reproduction. *Journal of Forensic Science* 35(4): 960–963.

Rocha S. dos S., Ramos D.L. de P. & Cavalcanti M.de G.P. 2003. Applicability of 3D-CT facial reconstruction for forensic individual identification. *Pesqui Odontol Bras* 17(1): 24–28.

Roelofse M.M., Steyn M. & Becker P.J. 2008. Photo identification: Facial metrical and morphological features in South African males. *Forensic Science International* 177: 168–175.

Rogers S.L. 1987. Reconstructing the face. In: *Personal Identification from Human Remains*. Charles C Thomas Publisher, pp 59–66.

Sahni D., Sanjeev, Singh G., Jit I. & Singh P. 2008. Facial soft tissue thickness in northwest Indian adults. *Forensic Science International* 176: 137–146.

Shimofusa R., Yamamoto S., Horikoshi T., Yokota H. & Iwase H. 2009. Applicability of facial soft tissue thickness measurements in 3-dimensionally reconstructed multidetector-row CT images for forensic anthropological examination. *Legal Medicine* 11: S256–S259.

Simpson E. & Henneberg M. 2002. Variation in soft-tissue thickness on the human face and their relation to craniometric dimensions. *American Journal of Physical Anthropology* 118: 121–133.

Smith S.L. & Throckmorton G.S. 2006. Comparability of radiographic and 3D-ultrasound measurements of facial midline tissue depths. *Journal of Forensic Science* 51(2): 244–247.

Snow C.C., Gatliff B.P. & McWilliams K.R. 1970. Reconstruction of facial features from the skull: An evaluation of its usefulness in forensic anthropology. *American Journal of Physical Anthropology* 33: 221–227.

Starbuck J.M. & Ward R.E. 2007. The affect of tissue depth variation on craniofacial reconstruction. *Forensic Science International* 172: 130–136.

Stephan C.N. & Henneberg M. 2001. Building faces from dry skulls: Are they recognized above chance rates? *Journal of Forensic Science* 46(3): 432–440.

Stephan C.N. 2002. Do resemblance ratings measure the accuracy of facial approximations? *Journal of Forensic Science* 47(2): 239–243.

Stephan C.N. 2003. Anthropological facial 'reconstruction' – recognizing the fallacies, 'unembracing' the errors, and realizing method limits. *Science and Justice* 42(4): 193–200.

Stephan C.N., Norris R.M. & Henneberg M. 2005. Does sexual dimorphism in facial soft tissue depths justify sex distinction in craniofacial identification? *Journal of Forensic Science* 50(3): 513–518.

Stephan C.N. 2006. Beyond the sphere of the English facial approximation literature: Ramifications of German papers on Western method concepts. *Journal of Forensic Science* 51(4): 736–739.

Stephan C.N. & Henneberg M. 2006. Recognition by forensic facial approximation: Case specific examples and empirical tests. *Forensic Science International* 156: 182–191.

Stephan C.N. & Cicolini J. 2008. Measuring the accuracy of facial approximations: A comparative study of resemblance rating and face array methods. *Journal of Forensic Science* 53(1): 58–64.

Stephan C.N. & Simpson E.K. 2008. Facial soft tissue depths in craniofacial identification (Part I): An analytical review of the published adult data. *Journal of Forensic Science* 53(6): 1257–1271.

Sutton P.R. 1969. Bizygomatic diameter: The thickness of the soft tissues over the zygion. *American Journal of Physical Anthropology* 30(2): 303–310.

Suzuki T. 1948. On the thickness of the soft parts of the Japanese face. *Journal of the Anthropological Society of Nippon* 60: 7–11.

Taylor K.T. 2001. *Forensic Art and Illustration*. CRC Press.

Taylor R. & Angel C. 1998. Facial reconstruction and approximation. In: *Craniofacial Identification in Forensic Medicine.* Britain: Arnold. pp 177–185.

Tedeschi-Oliveira S.V., Melani R.F.H., de Almeida N.H. & de Paiva L.A.S. 2009. Facial soft tissue thickness of Brazilian adults. *Forensic Science International* 193(127): 1–7.

Tilotta F., Richard F., Glaunès J., Berar M., Gey S., Verdeille S., Rozenholc Y. & Gaudy J.F. 2009. Construction and analysis of a head CT-scan database for craniofacial reconstruction. *Forensic Science International* 191(112): 1–12.

Turner W.D., Brown R.E., Kelliher T.P., Tu P.H., Taister M.A. & Miller K.W. 2005. A novel method of automated skull registration for forensic facial approximation. *Forensic Science International* 154(2-3): 149–158.

Turner W., Tu P., Kelliher T. & Brown R. 2006. Computer-aided forensics: Facial reconstruction. In: Westwood J.D. *et al.* (eds.) *Medicine Meets Virtual Reality*. IOS Press. 14: 550–555.

Tyrrell A.J., Evison M.P., Chamberlain A.T. & Green M.A. 1997. Forensic three-dimensional facial reconstruction: Historical review and contemporary developments. *Journal of Forensic Science* 42(4): 653–661.

Vandermeulen D., Claes P., Loeckx D., De Greef S., Willems G. & Suetens P. 2006. Computerized craniofacial reconstruction using CT-derived implicit surface representations. *Forensic Science International* 159S: S164–S174.

Vanezis P., Blowes R.W., Linney A.D., Tan A.C., Richards R. & Neave R. 1989. Application of 3-D computer graphics for facial reconstruction and comparison with sculpting techniques. *Forensic Science International* 42: 69–84.

Vanezis P., Vanezis M., McGombe G. & Niblett T. 2000. Facial reconstruction using 3-D computer graphics. *Forensic Science International* 108: 81–95.

Wilkinson C. 2004. *Forensic Facial Reconstruction*. Cambridge University Press.

Wilkinson C. 2005. Computerized forensic facial reconstruction: A review of current systems. In: *Forensic Science, Medicine and Pathology*. Humana Press Inc. pp 173–177.

Wilkinson C. 2007. Facial anthropology and reconstruction. In: Thompson T. and Black S. (eds.) *Forensic Human Identification: An Introduction.* CRC Press, pp 231–251.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

APPENDIX A
CT scan measurements – Data capturing sheet

Pt #					
Age					
A					
B					
C					
D					
E					
F					
G					
H					
I					
II					
J					
JJ					
K					
L					
M					
N					
O					
P					
Q					
R					
S					
T					
U					
V					
W					
X					
Y					
Z					

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

APPENDIX B
Results - CT scan measurements

PATIENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
AGE	**27**	**23**	**31**	**34**	**24**	**31**	**33**	**19**	**30**	**25**	**18**	**31**	**26**	**27**	**32**	**28**	**31**
A	4.0	4.0	4.1	4.1	4.0	4.0	4.5	4.1	5.0	4.1	3.8	4.1	3.0	4.1	5.1	6.0	4.1
B	6.1	5.6	5.0	4.8	8.0	3.7	6.1	6.0	6.1	6.1	5.4	5.0	5.1	7.0	5.1	8.1	7.2
C	5.0	5.5	3.1	3.3		4.9	7.1	6.1	6.9	5.4	3.2	5.4	4.1	4.1	7.1	4.8	6.9
D	2.2	2.4	2.8	2.4		4.2	2.8	3.6	3.6	1.4	1.4	2.2	2.2	2.1	2.2	2.0	2.4
E	2.8	4.5	2.6	2.6	2.9	5.7	2.5	3.6	3.2	2.0	3.9	5.3	5.1	4.2	3.5	4.8	2.9
F			8.4					8.2		8.7				9.4			
G																	
H	8.5	10.8	7.2	10.8	8.6	7.6	11.4	9.4	11.2	10.3		9.0	10.3	11.4	10.2	11.2	8.9
I	10.8	12.6	12.1	10.8	10.8	9.8	10.8	12.5	11.2	11.7		12.1	10.8	14.1	13.3	13.4	12.0
II	8.6	10.2	10.8	11.4		12.0	8.5	9.8	10.0	9.1		9.2	7.3	11.2	12.0	10.4	8.1
J	14.2	9.4		9.4	11.4	14.1	11.4	15.3	10.6	14.3			12.0	13.0		16.1	15.2
JJ	14.8	12.5		14.2		12.8	13.0	14.3	12.5	11.2			9.5	11.4		12.5	12.6
K	10.6	10.8		13.6	14.3	13.9	15.6	14.0		10.4			11.0	9.1			11.2
L				10.8	12.1	11.7	10.7	6.7						10.0			11.7
M					5.6	7.0	5.5										
N	5.4	3.9	2.5	4.3	3.5	6.1	5.0	3.9	3.8	3.5	4.4	5.6	2.4	5.1	4.7	3.9	3.8
O	3.8	3.3	4.6	4.2	3.7	4.3	4.6	3.6	4.1	3.1	3.6	4.6	4.1	4.8	4.7	4.3	2.6
P	6.3	5.9	5.5	5.4	8.2	6.6	5.7	4.9	7.2	7.5	5.9	7.3	5.3	6.9	7.6	6.3	6.7
Q	7.7	5.0	4.3	5.5	6.1	4.9	3.9	3.7	9.1	4.5	5.5	7.7	5.3	9.2	3.7	5.0	6.2
R	20.4	7.1	14.9	19.6	16.6	20.9	17.2	18.3	19.0	16.2				20.1	12.9	16.4	
S	7.0	5.9	6.3	6.5	4.5	5.8	10.8	4.9	10.0	6.4	5.9	6.6	7.4	8.6	9.9	11.1	10.5
T	15.6	11.2	12.5	13.7	10.9	9.9	12.1	9.8	10.8	11.9	10.2	9.8	11.5	9.8	11.2	12.7	11.8
U	23.3	20.7	19.4	21.6	15.4	16.3	19.4	16.3	21.2	20.2	16.4	11.5	16.7	16.4	17.3	23.8	17.7
V	21.4	18.4	20.7	22.3	18.2	19.0	24.9	18.8	23.1	18.7	18.9			19.2	23.1	26.0	22.3
W																	
X			20.8				30.3	24.4		28.5				29.8			
Y																	
Z							26.5	17.8						22.2			

APPENDIX B
Results - CT scan measurements

PATIENT	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
AGE	**28**	**35**	**18**	**21**	**32**	**31**	**28**	**23**	**24**	**18**	**18**	**30**	**34**	**23**	**31**	**23**	**25**
A	4.1	4.0	3.0	4.0	3.0	6.1	4.1	4.1	4.6	5.0	6.1	4.5	3.6	5.1	4.1	5.0	6.1
B	5.1	8.1	4.5	6.1	4.0	8.1	5.1	6.0	5.0	5.8	5.7	6.1	6.6	5.8	5.0	5.1	6.3
C	7.3	5.2	4.1	5.8	3.7	4.7	7.5	4.1	5.9	7.1	5.4	5.1	3.4	2.2	4.2	5.1	6.7
D	2.2	3.5	1.4		1.4	3.5	1.4	1.4	2.2	3.2	2.0	2.2	5.1	6.5	2.1	2.8	3.8
E	4.2	4.6	2.5	7.1	2.9	5.6	4.2	4.5	3.6	4.8	5.4	4.6	2.7	3.9	3.7	3.9	6.3
F		8.8	11.6		8.5							7.9		9.2	8.7		11.6
G			10.2									9.3		12.7			
H	10.4	9.4	12.2	14.1	11.4	11.3	9.4	10.3	14.1	13.2	10.5	9.2	11.2	10.8	10.3	11.7	9.2
I	13.0	12.4	17.2	15.3	7.6	14.2	11.7	14.6	16.1	14.1		12.8	10.8	13.0	13.0	13.9	13.0
II	10.0	10.0	10.8	13.2	5.1	10.3	8.2	13.2	15.0	12.2		10.0	7.3	11.0	12.6	10.8	9.4
J	14.6		16.1	15.8	10.4	17.0		13.4	16.6	17.0		14.8	12.2	13.6	14.8	14.4	16.0
JJ	12.4	12.6	15.3	12.8	10.0	13.9	11.0	12.4	16.6	15.0		12.6	10.8	11.6	14.4	12.5	13.6
K	11.3	10.2	10.2	15.3	11.1	16.1	11.0	10.8	12.1	11.2		10.2	13.2	10.8	10.3	9.5	13.4
L	10.8	10.0	10.0	10.8	6.1	9.5						10.0	9.2	11.2		9.8	12.4
M	5.4		4.1	7.1		6.3						5.1	4.6	8.5		6.1	
N	4.7	5.7	5.2	4.1	4.3	5.9	4.4	3.4	4.3	5.1	3.6	5.4	4.8	3.3	5.4	4.0	5.8
O	3.4	4.6	4.0	6.8	3.1	8.6	5.0	2.9	3.7	5.1	3.8	5.3	3.9	4.2	5.7	4.5	7.7
P	6.7	8.6	6.7	8.1	5.4	9.0	4.7	6.4	7.4	6.7	7.7	8.1	6.0	6.9	6.6	6.5	9.5
Q		5.6	5.3		6.4	8.6	5.7	6.2	7.8			10.7	5.9	10.9	6.6	6.7	11.3
R		18.5	17.6		14.2	25.1		17.3				20.2	17.5		22.1	19.1	23.6
S	7.4	4.8	6.4	14.8	3.7	12.1	5.0	7.2	6.8	11.9	7.7	8.2	5.9	7.6	9.2	11.0	12.5
T	11.3	15.1	10.3	12.8	8.6	15.2	12.5	12.8	14.7	12	11.5	11.9	12.2	12.7	14.7	9.1	15.2
U	16.4	15.6	20.7	23.1	9.3	21.2	17.6	17.9	20.1	18.2		15.7	21.3	20.9	24.1	18.1	22.6
V		20.3	24.3		12.1	23.9	21.6	22.3	21.4			21.1	21.4	23.6	23.5	22.5	26.8
W			11.1									16.8		24.8			
X		24.9	29.7			31.1						29.8		34.0	32.8		37.6
Y			22.9									18.6		19.4			
Z			22.2									20.6		21.9			31.4

APPENDIX B
Results - CT scan measurements

PATIENT AGE	35 26	36 27	37 25	38 27	39 25	40 32	41 21	42 26	43 19	44 26	45 30	46 23	47 34	48 23	49 34	50 28	51 28
A	4.1	5.1	4.3	4.1	5.1	3.2	5.1	4.1	4.1	4.1	4.0	3.2	5.3	8.1	4.1	5.1	6.1
B	6.7	7.1	4.5	6.3	7.3	7.2	5.1	6.6	6.5	7.6	8.1	4.1	4.9	7.3	6.6	4.1	5.8
C	6.3	5.9	4.4	6.2	7.2	7.2	6.5	5.6	6.6	4.8	6.5	4.6	4.5	8.7	5.1	3.6	5.3
D	2.4	2.3	3.0	2.0	2.8	2.2	2.5	6.0	3.6	3.2	2.4	2.2	3.3	3.6	2.6	3.2	2.1
E	4.5	5.7	4.4	3.1	4.1	6.5	4.5	4.1	5.8	3.6	4.5	3.2	4.8	8.2	2.6	4.0	4.2
F			11.1	9.8	11.3				13.4			8.1	12.0	12.7			
G			7.1							13.2							
H	10.8			11.7	14.3	9.5	12.1	10.6	10.8	12.8	12.2	11.2		12.1	10.8	7.6	11.2
I	13.2			12.2	15.3	13.5	13.9	11.2		13.6	14.6	14.6		15.0	10.8	10.9	
II	10.0			10.0	12.6		10.8	8.2		9.5	12.2	13.2		11.0	9.2	8.2	
J				16.0	14.9		15.3	14.3		16.1		15.1		16.5	11.2		
JJ	14.3			13.6	12.1		13.7	12.6		14.1		13.0		15.1	9.2		
K				13.6			11.4	11.2				10.8	12.6	14.3	10.8		
L				10.2				11.0				9.9	10.8				
M												5.6	6.1				
N	4.8	6.2	5.5	4.1	6.0	2.8	4.5	4.3	6.2	6.3	6.7	2.7	7.9	8.1	3.8	6.1	4.7
O	4.4	5.3	5.6	3.6	4.6	2.8	4.5	2.3	6.0	5.5	5.0	3.2	7.0	7.4	3.6	5.4	4.2
P	8.7	8.3	6.6	5.5	6.7	6.5	8.7	5.5	6.9	5.3	8.4	5.6	8.5	9.9	6.2	8.2	7.7
Q	7.4	8.9	4.5	3.1	8.3		6.4	6.8	8.1	7.8	7.5	4.2	7.7	12.9	5.5		7.9
R	21.1		18.1	16.4	21.6		17.3	18.1	22	18.8	20.3	17.3	17.7	24.8			
S	11.3	12.0	8.6	9.6	9.5	6.3	8.5	4.9	8.4	9.1	10.7	6.0	8.7	17.2	7.5	9.2	9.0
T	9.9	12.1	11.1	11.0	12.9	14.1	11.2	8.6	11.7	14.0	13.7	11.7	14.3	17.1	9.8	11.3	9.8
U	23.8	19.5	16.8	21.5	21.4	17.2	21.8	15.3	20.6	22.8	22.0	18.8	19.5	28.4	14.5		
V	25.3	27.7	21.8	24.0	22.8	18.8	25.3	16.7	23.6	25.2	23.6	21.0	21.2	34.9	19.6		
W													16.6				
X			33.1	33.6	36.3				33.5		33.2		32.5	37.8			
Y																	
Z									24.9		21.3						

APPENDIX B
Results - CT scan measurements

PATIENT AGE	52 22	53 31	54 31	55 21	56 32	57 32	58 20	59 35	60 35	61 22	62 20	63 25	64 33	65 27	66 29	67 30	68 34
A	4.0		2.8	5.0	6.7	5.1	3.0	4.1	3.2	4.1	6.3	4.5	4.0	5.0	7.0	6.1	6.3
B	4.0	5.6	7.1	6.6	7.6	7.0	6.7	5.1	5.1	5.1	10.0	4.0	4.1	6.1	6.6	8.2	7.6
C	3.5	5.0	7.1	5.1	8.8	4.7	7.6	4.1	5.4	5.1	6.0	5.4	5.8	7.1	6.1	5.4	7.4
D	1.8	2.9	3.1	3.2	2.7	3.5	1.4	1.4	2.2	2.6	2.2	2.2	2.2	3.2	4.8	2.3	2.8
E	2.8	4.3	2.1	3.9	5.7	4.8		2.8	5.0	4.6	4.3	4.7	3.4	3.8	4.1	4.1	5.5
F	9.0	10.1				11.0			11.0			10.8		10.6	14.0	9.9	11.4
G		12.8													14.8	13.3	
H			8.6	12.2	10.8	10.0	10.0	7.8	10.6	11.7	12.0	11.2	10.0	12.0		10.8	12.2
I			11.0		12.0	15.3	12.6	10.4	12.4	13.3	14.3	11.4	12.4	16.4		14.9	14.6
II			7.1		9.1	12.2	7.1	7.3	6.7	10.2	11.4	10.2	10.4	12.6		13.3	12.0
J						15.0	15.0		12.4	14.8		13.0	14.9	16.1		16.2	
JJ						14.8	12.8		12.2	13.9	13.6	11.2	13.4	14.6		14.1	
K						10.8	11.4		12.2			12.2	10.3	12.7		14.9	14.3
L							9.8		9.4			9.2		11.0		10.6	10.0
M												8.2		7.5		9.0	
N	4.5		3.3	5.1	5.0	5.6		5.1	4.8	4.0	5.7	4.3	3.0	5.3	7.1	5.2	7.0
O	2.8		3.5	5.3	4.6	4.2		3.6	4.4	4.6	5.7	4.4	4.4	4.0	6.1	6.0	6.2
P	5.1	8.6	6.4	6.4	8.7	6.3		5.2	5.8	6.7	9.3	6.3	5.4	6.5	6.9	7.2	8.5
Q	4.0	10.8	6.7	5.7	5.0	5.9		4.6	7.4	5.2	6.5	6.7		7.9	11.8	6.8	8.2
R	12.3	21.9							16.2	17.3	18.8	18.2			21.1	16.8	21.0
S	5.5	9.0	6.3	8.2	11.5	5.9		6.2	5.8	8.1	16.0	6.6	7.8	8.1	11.3	10.2	12.3
T	10.2	12.9	10.2	10.6	12.2	12.7		7.8	9.6	12.3	16.4	10.8	11.0	10.7	14.0	13.9	17.0
U	13.6	21.2		17.6	22.5	15.7		14.8	14.8	20.8	26.7	17.0		22.4	16.0	20.5	23.0
V	15.3	22.6		19.6		16.8		19.7	17.3	23.4	28.8	19.8		24.3	20.4	25.1	28.1
W		23.8													15.6	16.4	
X	25.1	26.5				29.5			24.4			28.8		36.7		28.2	33.8
Y		16.1														18.3	
Z	15.9	19.6														22.8	

APPENDIX B
Results - CT scan measurements

PATIENT AGE	69 24	70 33	71 26	72 22	73 33	74 29	75 26	76 34	77 30	78 34	79 27	80 24	81 27	82 18	83 31	84 32	85 21
A	3.2	4.1	6.1	7.1	3.2	4.0	6.3	6.2	3.5	4.5	6.1	8.0	5.0	4.7	4.0	4.0	4.5
B	8.2	8.1	7.3	6.7	5.4	6.7	5.7	6.0	5.4	7.1	6.6	7.1	5.8	5.9	6.8	8.1	6.7
C	4.3	4.7	5.8	6.9	8.9	5.8	7.8	5.9	7.2	4.5	7.8	7.6	8.1	5.9	5.1	5.4	5.4
D	1.4	1.6	3.1	5.3	2.2	2.4	2.2		2.2	4.1	3.6	4.5	2.2	3.1			2.2
E	4.6	3.7	5.4	5.4	4.3	2.9	6.0	3.6	4.9	3.3	3.6	5.6	4.0	3.9	4.7	4.5	4.3
F										10.8		9.0			8.7		
G														10.8			
H	11.4	12.2	14.4	10.8	8.5	10.3		12.0	12.0	12.5	14.8		12.5		11.4	9.8	10.3
I	14.1	13.6	13.2	13.9				14.3	15.0	15.0	14.3			14.1	13.6	14.3	
II	12.0	10.4	9.1	10.2				9.8	12.0	11.0	10.7			13.2	9.2	11.0	
J				16.1		13.9			16.1	16.1	14.3			15.1	16.6		
JJ				13.4		13.6			13.5	15.7	10.4			14.3	14.6		
K						12.0			12.0	10.3	12.5				11.7		
L						10.0											
M						6.6											
N	3.7	3.6	4.9	5.0	4.0	4.5	4.6	5.2	4.1	4.3	4.9	6.5	4.7	4.9	4.5	3.8	3.4
O	3.6	4.4	4.6	5.1	2.5	4.2	4.6	5.0	4.0	4.4	3.7	4.3	3.9	4.7	4.8	3.9	3.5
P	7.2	6.5	7.8	7.3	4.6	6.2	6.9	8.2	4.5	8.4	4.5	9.2	6.4	8.2	6.5	5.4	6.9
Q	6.5	6.3	7.8	9.5	5.1	4.2	6.8	6.3	5.2	8.2	5.7	9.2	4.4	9.0	5.2	6.3	7.0
R		20.0	21.5	19.7		15.7		20.1	15.9		16.4	21.4			16.1		
S	5.6	8.3	11.1	8.6	4.8	8.4	9.4	8.8	7.0	7.8	6.3	6.7	9.2	11.2	7.0	7.3	8.0
T	8.1	14.3	12.3	11.3	9.8	11.1	13.7	13.0	9.7	10.2	9.8	13.9	12.8	10.6	10.6	11.8	11.3
U	15.1	21.2	21.9	21.1	17.0	20.6	22.8	19.2	17.5	14.4	15.4	23.9	18.3	22.7	19.0	19.1	20.8
V	21.1	21.9	26.4	25.0	18.0	20.2	24.0	22.4	22.2	20.8		25.2		27.4	19.7	23.2	19.1
W												21.7					
X										31.5		31.0			27.8	28.6	
Y												24.7					
Z												23.4					

APPENDIX B
Results - CT scan measurements

PATIENT	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102
AGE	**23**	**22**	**34**	**34**	**21**	**24**	**33**	**29**	**23**	**34**	**33**	**32**	**22**	**24**	**32**	**27**	**32**
A	3.4	5.8	5.4	3.0	4.5	4.2	5.0	5.4	4.1	3.0	3.4	4.5	4.1	3.9	5.1	3.7	5.4
B	4.2	7.6	8.1	6.7	5.1	6.0	6.7	8.1	5.4	5.0	7.0	7.1	5.1	5.6	6.3	5.1	6.3
C	4.6		7.1	5.4	4.5	4.1	5.0	5.8	8.2	3.6	7.1		6.3	6.7	6.4	6.7	
D			3.6	2.2	2.8		3.2	2.9	2.2	3.2	2.6		2.2	2.3	2.5		
E	3.6	5.4	5.1	2.7	3.8	3.3	4.9	5.7	2.7	4.8	3.0		5.1	3.7	4.6	3.3	
F			8.2	10.2	11.8	9.7	8.2	12.3			9.5			9.3			14
G		13.9				10.1											
H	9.2	11.4	10.8	11.2	11.7	9.2	9.2	11.4	10.8		11.3	13.6		10.8	11.7	10.8	
I		15.8	10.8	12.4	13.6	9.2		14.3	13.0		12.5			12.6	14.3	15.3	
II		12.5	7.6	8.2	10.2	8.6	5.4	11.7	10.0		9.8			8.2	9.2	10.4	
J		14.0	15.2	13.0	14.9	10.4		16.8	14.8		14.3				15.6		
JJ		14.0	13.9	11.7	13.9	10.0	12.5	15.8	14.4		13.3				14.9		
K		16.1	16.3	11.2	10.3	9.2	13.3		13.6		10.2	12.5			12.8		16.8
L		12.0		9.8	9.8	8.1	17.1		10.0			16.1					10.6
M		7.5			8.0	4.0	6.1		6.1			8.1					7.1
N	3.8	5.8	5.8	2.7	4.3	4.3	6.2	5.6	3.3	2.7	4.5		6.3	2.4	6.2	3.1	
O	3.7	6.1	3.9	3.0	4.9	3.9	4.6	5.0	5.7	3.4	3.4		5.9	2.5	5.2	2.8	
P	5.2	7.4	8.3	6.5	6.8	4.9	8.0	7.6	6.4	4.3	7.6		8.8	6.1	7.3	4.0	
Q	4.2	8.6	10.9	4.7	8.9	5.8	12.3	10.3	5.2		5.3		7.9	8.6	6.7	3.5	
R			18.0	13.0	19.9		19.2		10.8		16.5	24.9		18.0			
S	6.8		8.0	3.4	8.4	4.6	8.2	11.5	5.5	6.7	6.8	13.4	11.3	7.5	8.6	4.8	9.0
T	10.7		13.5	9.2	12.8	9.5	12.5	14.9	10.7	12.8	9.8	16.1	14.8	9.1	10.6	7.9	16.6
U	17.2	20.0	20.5	13.4	22.9	14.0	16.8	21.0	19.9	19.0	13.8	27.1	25.8	17.4	15.9	19.2	26.2
V	19.4	20.3	22.5	17.6	26.3	16.1	17.1	25.5	21.4		17.8	31.5	27.8	19.8		19.5	26.6
W		19.8				12.3			11.2			19.0	13.0	21.2			13.2
X		35.5	35.6	27.3		25.3	27.9	36.0			25.4	23.5	28.4	28.5		22.5	22.7
Y		26.3				14.3	19.9					22.6	13.4				25.1
Z		21.4	22.9	17.5		15.1	15.5				14.3	28.3	18.5	21.4			21.5

APPENDIX B
Results - CT scan measurements

PATIENT	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119
AGE	**27**	**18**	**18**	**24**	**28**	**33**	**27**	**20**	**33**	**29**	**20**	**26**	**27**	**23**	**32**	**27**	**27**
A	4.1	3.0	3.2	5.7	3.0	5.8	5.1	6.3	5.4	3.6	4.0	5.6	5.4	4.1	3.4	4.1	5.0
B	7.1	4.5	8.1	7.0	5.4	7.1	7.1	6.3	6.3	5.0	5.8	7.3	6.1	5.4	5.6	5.1	5.4
C	7.1	5.0	8.6	6.7	5.8	7.3	7.6	7.3	5.1	5.6	3.2	7.3	6.3		6.3	7.1	7.3
D	2.2	1.8	1.8	2.2	2.2		3.5	2.8	2.5	2.8	2.2	2.6	2.8	2.2	1.4	2.4	2.2
E	3.1	3.8	3.9	4.6	3.1	6.5	4.7	6.7	3.7	3.7	3.6	3.9	4.1	2.8	2.9	3.6	3.0
F	11.5	10.2		10.9	9.3			11.0		9.9			10.6				
G																	
H	11.2	12.5	9.5	10.8	9.0	12.8	10.5	12.0	10.3	11.3	10.8	9.5	10.3	9.2	9.8	11.2	9.2
I	14.9	14.3	12.4	14.3	13.2	12.1	16.3	15.7	12.0	13.3	12.0	13.6	13.6	12.2			13.3
II	10.2	11.2	9.1	10.2	9.0	9.4	13.0	11.7	8.6	9.5	8.1	12.0	11.0	9.1			11.7
J	16.1	13.0	15.3	15.3	16.6	16.0	16.2	16.0		13.0	15.2	14.8	13.4	15.2			14.8
JJ	14.3	12.4	13.6	13.6	14.8	15.0	14.3	15.3		13.3	13.9	13.4	13.4	13.9			13.0
K	11.7	10.3	11.7	9.2	12.8	16.1	10.4	15.3		9.1	10.3	11.2		13.9			10.0
L	11.2	9.5	7.6	7.8		15.0		9.9		8.2		11.4					
M	10.0	7.0	5.1	6.0				7.5									
N	6.4	4.0	5.3	5.1	3.7	6.6	5.2	6.2	4.6	5.5	4.7	2.9	5.8	2.8	4.0	4.8	4.0
O	5.8	3.3	3.9	4.7	3.9	8.5	5.0	5.5	5.9	5.2	3.0	3.0	5.1	3.8	2.9	4.6	3.6
P	8.4	5.2	6.5	9.2	4.6	8.1	7.4	8.5	7.8	5.5	6.5	5.1	7.4	6.2	4.7	5.4	4.0
Q	8.0	5.9	6.5	4.8	5.2	13.7	10.8	10.4	5.2	6.9	4.3	3.3	6.4	4.6	4.1	3.4	3.5
R	21.4	16.9			12.3	26.0		20.5				18.2	19.1				
S	12.1	4.7	6.7	7.9	9.0	11.0	9.8	12.0	12.1	7.0	8.0	5.1	9.9	9.0	4.9	9.1	4.8
T	12.9	10.1	10.6	10.9	12.5	14.5	11.4	13.2	13.3	9.0	9.7	10.8	11.6	13.5	8.1	12.2	9.4
U	24.3	16.9	15.0	17.6	18.9	29.1	19.7	20.5	24.1	17.6	20.6	15.4	20.2	22.9	12.1	17.7	14.5
V	27.4	19.5		23.6	19.8	29.5		24.2	26.4	22.5	23.5	17.1	21.6	23.9			17.8
W					16.0												
X	35.3	26.2		31.3	29.3	35.5		35.3		28.2			28.7			27.5	
Y					25.4			25.3									
Z					21.0			24.2		22.7			19.9			19.2	

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

APPENDIX B
Results - CT scan measurements

PATIENT	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136
AGE	35	29	28	24	33	34	30	33	21	23	35	22	29	35	30	25	24
A	6.7	3.0	7.6	5.3	4.1	6.3	6.0	5.4	4.3	3.7	3.0	5.1	2.0	4.8	4.5	4.5	6.0
B	9.8	5.1	6.7	6.1	6.4	5.8	7.1	7.1	6.3	5.0	5.4	7.3	5.4	7.6	7.3	6.3	9.1
C	6.3	5.1	7.6	4.4	8.9	5.3	5.7		7.3	5.1		6.4	5.0	7.2	5.5	6.1	
D	2.8	2.2	2.0	2.2	3.2		3.2	2.8	2.2			2.2	2.4	3.3	3.3	2.2	8.2
E	4.2	3.3	5.0	4.5	6.3		5.7	5.6	3.5	3.2	5.4	3.9	4.5	3.4	4.8	5.8	5.0
F			11.4		10.8		7.6	7.4							10.0		
G					17.4											11.5	
H	12.7	10.3	11.7	12.2	12.0		10.8	10.4	12.1	8.1	12.2	11.2	11.2	11.2	12.0	10.8	11.7
I	14.8	11.2			12.9		13.3	13.2	12.0	12.4	14.0		13.2		17.7	12.0	14.6
II	10.3	7.1			10.6		11.0		12.0		11.4		10.0		11.7	8.6	10.4
J	14.0	12.5			13.6		15.2		15.6						16.0	16.0	18.0
JJ	12.0	12.1			13.6		13.4		15.3						14.3	13.9	13.9
K	14.9	10.8			13.2		14.4									12.6	
L	14.1	10.3			12.0		11.2									12.6	
M	9.8	5.1			6.6											7.0	
N	7.7	2.8	5.9	4.3	5.9	7.7	5.5	5.8	3.8	4.6	3.5	4.9	2.3	2.9	4.6	3.5	4.3
O	7.7	2.5	4.5	4.2	5.4	7.5	5.1	5.2	2.9	4.0	2.9	5.1	2.8	3.8	3.5	4.9	6.6
P	6.0	5.5		7.0	6.7		6.8	8.7	5.6	5.1	5.4	7.1	4.8	5.1	8.4	7.2	8.5
Q	12.3	4.7	10.3	4.8	9.1	12.6	6.7	4.5	4.2	4.2	6.5	8.1	3.5	6.9	7.5	6.0	8.5
R	25.4	16.4	21.3		21.0		14.3		14.3						19.6		
S	19.9	7.5	8.4	9.0	12.7	8.5	6.1	10.8	5.1	6.7	6.5	6.0	4.7	8.9	7.9	9.5	12.4
T	19.2	11.3	11.0	13.4	16.5	12.2	10.6	13.8	10.6	11.4	13.3	11.4	12.4	11.2	10.7	16.5	14.1
U	28.9	17.6	21.0	18.0	18.8	26.2	18.5	24.4	17.0	18.1	22.0	19.2	16.5		18.1	19.4	29
V	34.1	21.3	24.6		20.6	26.3	19.6	24.1	18.8	19.6	17.4		17.4	23.3	24.4	22.2	30.2
W					15.0											24.9	
X	36.2		34.9		32.5	29.3	31.8	30.3	25.3						23.7	30.1	
Y					24.4											18.6	
Z	30.7				22.2		22.3		18.5							22.1	

APPENDIX B
Results - CT scan measurements

PATIENT	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153
AGE	26	33	35	20	23	32	28	35	30	26	27	27	27	27	34	32	34
A	5.0	6.3	4.5	7.3	3.5	4.1	3.6		6.4	8.1	5.2	4.1	3.6	5.3	6.3		5.8
B	5.1	7.1	6.3	7.3	3.1	7.6	7.6	7.3	7.1	10.5	7.3	5.4	5.4	5.0	9.1		4.7
C		6.0	5.7	8.1	3.8		7.2		10.0	12.0	6.6	6.4	9.2	7.0	10.0		7.3
D	2.8	2.6	2.2				2.8	2.8			3.4	2.2	2.8	2.7	3.6		2.5
E	5.3	4.6	3.1	5.6	3.4	7.6	5.6	4.4		6.0	5.4	4.2	3.0	3.9	3.0	3.9	3.5
F	7.2	10.4		14.5				11.6		10.7			8.9	9.1		9.1	
G				16.2				14.6		15.5				11.0			
H	11.4	10.6	10.4		9.2	9.2	11.7	13.0	12.7	10.8	10.8	10.3	11.2	10.3	12.5	10.3	12.4
I	10.5	14.3	12.0		12.8	12.9	13.3	15.1	17.5	13.6	16.5	14.1	14.0	15.3	15.1		17.3
II	8.0	9.8	8.1		9.8	11.4	10.0	12.0	18.0	8.2	13.0	10.7	10.0	12.5	11.2		15.0
J	14.1	15.5			13.2	15.6	13.9	14.6	21.5	15.5	14.3	13.4	14.3	12.5	16.1		18.7
JJ	12.4	15.0			13.0	12.8	12.1	13.9	21.5	13.8	13.9	13.0	11.7	11.7	14.2		17.0
K	10.4	10.7		15.7	13.0	12.0	12.0	15.5	10.3	16.6	11.7	10.8	9.4	13.5	13.6		12.1
L	9.5			9.8	9.1	9.9	11.7	13.0	13.2	8.5	11.7	12.5	10.3	9.4	10.3		10.3
M					5.4	7.1		7.1	8.1	5.0		9.1	6.1	8.3			6.7
N		7.5	4.6	6.5	4.5	5.2	4.9	4.0	6.4	8.3	5.0	2.8	4.0	4.7	4.5	2.7	5.2
O		7.7	5.1	6.4	5.1	5.4	5.6	5.2	7.4	9.1	5.2	3.3	4.0	4.3	3.0	3.7	8.6
P	7.2	9.4	5.9	8.9	5.1	9.0	8.3	7.3	8.7	9.9	7.6	5.4	4.9	7.2	7.6	7.1	7.9
Q	4.3	12.0	5.1	9.0	5.3		7.5	9.0		10.9	11.3	7.1	9.8	6.9	4.2	7.2	6.3
R		25.7		21.7	17.9			21.7			23.3		15.7	18.8		19.0	
S	4.8	12.3	7.7	11.6	5.1	9.8	10.5	14.3	8.3	13.5	10.6	6.3	5.9	7.8	5.5	5.7	11.3
T	10.2	15.1	11.2	12.0	8.1	13.0	13.7	14.4	17.0	17.2	11.6	11.3	7.6	13.2	11.3	11.3	12.2
U	12.5	20.6	17.9	21.3	13.9		22.8	21.2	24.2	25.2	21.1	19.2	17.5	19.2	21.8	25.4	19.0
V	17.5	26.3		25.4	21.1			22.5	25.2	25.4	25.6	20.5	20.4	22.1	21.2	26.4	26.6
W				15.8	19.4	21.4		27.4	19.5	15.9				15.6			17.9
X	23.3	36.9		25.5	20.1			31.3	36.1	36.3			29.3	27.5		33.8	32.4
Y		28.7		22.8	16.6			18.9	27.7	25.3			17.8	23.9			24.7
Z	16.2	27.3		23.7	15.7			22.6	25.2	24.5			16.7	22.6		21.3	24.9

APPENDIX B
Results - CT scan measurements

Measurement	n 153	Mean 27.582	SD	Mode 27	Min 18	Max 35
A	150	4.677	1.185	4.1	2.0	8.1
B	152	6.279	1.287	5.1	3.1	10.5
C	141	6.003	1.552	7.1	2.2	12.0
D	132	2.716	0.975	2.2	1.4	8.2
E	148	4.264	1.132	3.9	2.0	8.2
F	59	10.186	1.672	8.7	7.2	14.5
G	17	12.612	2.713	-	7.1	17.4
H	138	10.916	1.409	10.8	7.2	14.8
I	121	13.300	1.761	14.3	7.6	17.7
II	118	10.315	1.958	10.0	5.1	18.0
J	95	14.654	1.912	16.1	9.4	21.5
JJ	99	13.391	1.673	13.9	9.2	21.5
K	91	12.205	1.988	10.8	9.1	16.8
L	64	10.608	1.910	10.0	6.1	17.1
M	42	6.719	1.455	6.1	4.0	10.0
N	148	4.749	1.256	4.3	2.3	8.3
O	148	4.602	1.348	4.6	2.3	9.1
P	148	6.841	1.371	6.5	4.0	9.9
Q	140	6.886	2.374	5.2	3.1	13.7
R	83	18.669	3.427	16.4	7.1	26.0
S	151	8.413	2.767	9.0	3.4	19.9
T	151	12.014	2.188	11.3	7.6	19.2
U	145	19.514	3.689	17.6	9.3	29.1
V	128	22.384	3.708	22.5	12.1	34.9
W	26	17.896	4.353	15.6	11.1	27.4
X	72	30.113	4.431	29.3	20.1	37.8
Y	25	21.668	4.254	18.6	13.4	28.7
Z	44	21.600	3.930	22.2	14.3	31.4

APPENDIX C
Consent form – Obtaining photos from students

PARTICIPANT INFORMATION LEAFLET AND INFORMED CONSENT

STUDY TITLE

DEVELOPMENT OF SOFT TISSUE THICKNESS VALUES FOR SOUTH AFRICAN BLACK FEMALES, AND TESTING ITS ACCURACY

INTRODUCTION

You are invited to volunteer for a research study. This information leaflet is to help you to decide if you would like to participate. Before you agree to take part in this study you should fully understand what is involved. If you have any questions, which are not fully explained in this leaflet, do not hesitate to ask the investigator. You should not agree to take part unless you are completely happy about all the procedures involved.

WHAT IS THE PURPOSE OF THIS STUDY?

Facial photographs will be used in an identification sessions where facial reconstructions has to be matched with photos. The purpose of the photos is to give a larger sample of photos for the participant in the identification session to choose from, so to see whether the participant could correctly identify the photo matching the reconstruction from a random selection of photos. Should you agree to participate, your contribution will help to determine the accuracy of forensic facial reconstructions used to identify unknown victims of crimes or drowning and other forensic cases.

WHAT IS THE DURATION OF THIS STUDY?

If you decide to take part, yours will be one of 20 photos. Your involvement will be to hand in the photo, whereafter the researcher will scan it for further editing and modification. These photos will then be used once, and then stored safely for 15 years for reference in any future studies. Your photo will not be damaged and returned to you unharmed a few days later.

HAS THE STUDY RECEIVED ETHICAL APPROVAL?

This Study Protocol was submitted to the Faculty of Health Sciences Research Ethics Committee, University of Pretoria and written approval has been granted by that committee. The study has been structured in accordance with the Declaration of Helsinki (last update: October 2000), which deals with the recommendations guiding doctors in biomedical research involving human/subjects.

WHAT ARE MY RIGHTS AS A PARTICIPANT IN THIS STUDY?

Your participation in this study is entirely voluntary and you can refuse to participate or stop at any time without stating any reason.

MAY ANY OF THE STUDY PROCEDURES RESULT IN DISCOMFORT OR INCONVENIENCE?

No

WHAT ARE THE RISKS INVOLVED IN THIS STUDY?

None

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ARE THERE ANY WARNINGS OR RESTRICTIONS CONCERNING MY PARTICIPATION IN THIS STUDY?
No

INSURANCE AND FINANCIAL ARRANGEMENTS

Before you participate, you should understand that there will not be any personal financial gain should you participate.

SOURCE OF ADDITIONAL INFORMATION

Should you decide, after your photo has been handed in, that you want to withdraw from the study, you may phone the investigator (D Cavanagh) at 012-4203256 to inform her of your withdrawal.

CONFIDENTIALITY
All information obtained during the course of this study is strictly confidential. Your facial photograph will not be published in any recognisable form. Sections of your photograph, e.g., nose, ear, or mouth may be published, but it will not be recognisable as a particular individual. Data obtained during this study will not be available for any other purposes and the photographs will only be available to the investigator for purposes of her MSc, and possibly later a PhD study. After this the photographs will be returned to the owner, and the scans will be destroyed.

INFORMED CONSENT

I hereby confirm that I have been informed by the investigator, D Cavanagh, about the nature, conduct, benefits and risks of this study. I have also received, read and understood the above written information (Participant Information Leaflet and Informed Consent) regarding the study.

I am aware that the photographs will be anonymously processed into a study report.

I may, at any stage, without prejudice, withdraw my consent and participation in the study. I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.

I agree that unrecognisable sections of my photograph may be published in the MSc thesis and scientific journals:

Yes _____________ No____________ (mark where appropriate)

Participant's name ________________________
(Please print)

Participant's signature ________________________ Date ______________________

Investigator's name ________________________
(Please print)

Investigator's signature ________________________ Date ______________________

I, D Cavanagh herewith confirm that the above person has been informed fully about the nature, conduct and risks of the above study.

Witness's name* _______________ Witness's signature __________________________
(Please print)

Date __________________

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

APPENDIX D
Scoring Sheet – Identification Session 1

STUDY TITLE:
DEVELOPMENT OF SOFT TISSUE THICKNESS VALUES FOR SOUTH AFRICAN BLACK FEMALES, AND TESTING ITS ACCURACY

PARTICIPANT DETAILS: (Please tick the appropriate choice)
Sex:

M	F

Race:

White	Black	Coloured	Indian

Other_____________

INSTRUCTIONS:
Each reconstruction is numbered with a letter of the alphabet from A to H. Please carefully study the photographs displayed at every reconstruction, numbered from 1 to 20, and decide on the best possible match to the reconstruction. Write down the number of that photo next to the letter of the relevant reconstruction. You may also put down the number of any other photos in the "any other possible matches" column, should you feel that there is more than one possible photo fitting the reconstruction. Please note that adding a second or third possible match is only **optional**. Should you feel that you can't identify a photo that matches the reconstruction at all, please write down the word "**none**" in the "most perfect match" column. Please note that some photos may repeatedly be a match to more than one reconstruction, thus you are allowed to choose the same photo more than once. In the "2D/3D" column, please state whether it was easier to make a match with the photo(s) from the 2D photo of the reconstruction(s) or from the 3D reconstruction(s) itself? In the "reason" column, please write down the feature(s) that made you decide on your choice of the matching photo(s), i.e. "facial shape", "proportions", "eyes", "nose", "mouth" etc. Please do not guess a photo, but take this identification session seriously. **Thank you** for your participation.

Reconstruction	Most perfect matching photo	Any other possible matching photos	2D / 3D	Reason(s)
A				
B				
C				
D				
E				
F				
G				
H				

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

APPENDIX D
Scoring Sheet – Identification Session 2

STUDY TITLE:
DEVELOPMENT OF SOFT TISSUE THICKNESS VALUES FOR SOUTH AFRICAN BLACK FEMALES, AND TESTING ITS ACCURACY

PARTICIPANT DETAILS: (Please tick the appropriate choice)
Sex:

M	F

Home language: ____________________

INSTRUCTIONS:
Displayed are reconstructions numbered 1 to 4, and photographs numbered A and B. Please carefully study the photographs and reconstructions, and decide on the reconstruction that best match the photo. Write down the number of that reconstruction next to the letter of the relevant photo. In the "2D/3D" column, please state whether it was easier to make a match from the 2D photo of the reconstruction(s) or from the 3D reconstruction(s) itself? In the "reason" column, please write down the feature(s) that made you decide on your choice of the matching photo(s), i.e. "facial shape", "proportions", "eyes", "nose", "mouth" etc. Please do not guess a reconstruction, and take this identification session seriously. **Thank you** for your participation.

Photograph	Most perfect matching reconstruction	2D / 3D	Reason(s)
A			
B			

APPENDIX E
Results – Identification session 1

	Number of times a photo was selected as match to the reconstruction																				
Photo number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Total**
Reconstruction: Skull A (Current study)	7	3	8	5	4	3	0	2	1	1	6	0	7	6	1	12	0	0	4	4	74
Skull A (Man 2000)	10	3	8	3	3	6	1	5	3	3	6	1	8	4	3	6	0	0	1	2	76
Skull A (P&S 1996)	2	3	11	4	3	0	3	1	0	2	4	2	3	5	5	8	0	3	2	6	67
Skull A (R&C 1980)	1	1	3	4	3	2	1	3	5	7	4	3	5	6	4	7	1	4	1	7	72
Skull B (Current study)	3	3	4	7	2	2	2	7	0	8	1	0	5	1	1	2	12	1	4	2	67
Skull B (Man 2000)	7	4	6	6	0	3	2	3	4	8	1	3	4	1	2	5	2	2	3	2	68
Skull B (P&S 1996)	1	1	5	4	3	5	4	2	3	9	0	9	7	0	10	0	7	2	0	0	72
Skull B (R&C 1980)	0	3	0	7	0	2	3	3	2	8	0	4	6	3	1	4	5	6	5	5	67
Total	31	21	45	40	18	23	16	26	18	46	22	22	45	26	27	44	27	18	20	28	

Man 2000 – Manhein *et al*. 2000
P&S 1996 – Phillips and Smuts 1996
R&C 1980 – Rhine and Campbell 1980

True positive photos at each reconstruction indicated with grey.

APPENDIX F
Results – Identification session 2

		Number of times a reconstruction was chosen as most alike to the photo				
		Reconstruction				
		Current Study	**Man 2000**	**P&S 1996**	**R&C 1980**	**Total**
Photo	**Individual 1 / Skull A**	17	7	0	6	30
	Individual 2 / Skull B	13	8	3	6	30

Man 2000 – Manhein *et al*. 2000
P&S 1996 – Phillips and Smuts 1996
R&C 1980 – Rhine and Campbell 1980