FACIAL FATNESS AS A COMPLICATING FACTOR IN FACIAL RECONSTRUCTION

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CLRCAR008

SUBMITTED TO UNIVERSITY OF CAPE TOWN

In fulfilment of the requirements for the degree

MSc (Anatomy)

Faculty of Health Sciences

University of Cape Town

Date: February 2015

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DECLARATION

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF GRAPHS

ABSTRACT

Although it is a reasonable assumption that a significant proportion of the variation in facial tissue thicknesses comes from anatomical differences between populations, we do not know how much of normal variation is caused by including the full range of individual obesity or slimness. Current population standard soft tissue thickness data used in facial reconstructions ignores the variation between individuals which, in theory, could be greater than the variation between populations or sexes.

The aim of this study was to test if facial tissue thickness is due to the amount of sub-cutaneous fat, sex or racial origins. Methods currently used do not give a true reflection of the individual because they ignore the variation in fatness.

An initial study determined if a corrective value for the non-linear distortion found between radiographic images and the physical tissues was needed. This was done by imaging cadaver heads and taking measurements from the images and the physical heads. The results demonstrated that measurements taken from LODOX® images are analogous with soft tissue measurements.

Volunteers were then sought from the student body and had physical measurements and X-rays taken. The measurements allowed for both BMI and body fat percentage to be calculated. Analysis showed that body fat percentage had less of an impact than BMI, with the areas of the face most affected by change in fatness being around the chin, jaw and cheek. Analysis of the variances showed that fatness has a low impact on the soft tissues of the different ancestry groups, while having a greater impact on the soft tissues of the different sexes.

The effect of changing fatness on the soft tissues is not seen in all areas of the face, but to ignore it in facial reconstruction ignores that the success of a reconstruction is not exactness but in its ability to incite recognition and lead to potential identification of the unknown target individual.

ACKNOWLEDGEMENTS

I would like to thank the National Research Foundation (NRF), Dr Friedling for offering me a place in the program, C. Harris for his skills in constructing the needle puncture mechanism, N. Karriem for her work with the LODOX Statscan, H. Carrara for the introduction to STATA and how to use it.

My heartfelt gratitude to those who supported me during the last few years, especially my family, for all their love and supporting me through it all; Samantha Orange, for her moral support and never-ending positivity; as well as Kyle Paulssen, Matthew Orange, Louwrens Hattingh, my fellow students and friends for all their support.

Further thanks and appreciation to my supervisors, and all those who expressed interest, spread the word and took part in this study, without whom it could not have happened. As well as the wonderful people I met and talked to at IFAA who expressed interest and support in this study.

1. INTRODUCTION

1.1. INTRODUCTION

Facial reconstruction, or facial approximation as it is also known, is a method of possible identification used when all other means of attempting to identify unknown skeletal remains have been exhausted. It is used in the contexts of archaeology, to construct representations of past peoples and human ancestors from skeletal and preserved remains; and forensic science, when post-mortem decomposition has complicated identification (Wilkinson 2010; Torres Muñoz *et al.* 2011). It is also a useful tool in the identification of victims of disasters, such as the 2004 Tsunami and Hurricane Katrina in 2005 (De Greef *et al.* 2006; Wilkinson 2010).

The technique of facial reconstruction is meant less as a definite representation of a particular person than as a means of inciting recognition from the public. Facial approximation is never used as a final means of identification but as a tool for recognition (De Greef *et al.* 2009; Wilkinson 2005). Instead, the reconstruction is presented as part of a campaign in the hope that it will incite recognition from the public (Wilkinson 2010). Final identification is based on information given by members of the public, or specific features of DNA or medical or dental history.

Modern reconstruction techniques have developed from research in Russia (Gerasimov 1971), the United Kingdom (Prag & Neave 1997), the United States of America (Gatliff 1984), Germany and Switzerland (Wilkinson 2005), where facial tissue thickness measurements were used to produce reconstructions of famous individuals, such as Johann Sebastian Bach and Friedrich Schiller (Prag & Neave 1997).

The process of reconstruction starts with a cast or three-dimensional (3D) digitised scan of the actual skull. The forensic anthropologist then places tissue depth markers at specific coordinates on the cast or scan. Facial features are constructed through manual clay manipulation or computer modelling following similar procedures as those used in the manual clay method (Kähler *et al.* 2003; Thomas 2003; Machers & Morris 2005; Wilkinson 2005; Decker *et al.* 2013).

The majority of research on soft tissue thicknesses of the face has used cadaveric samples and in the past data have been gathered using the needle puncture technique; where a thin, sharp needle is used to pierce the skin and a rubber stopper on the needle is displaced upwards during this action which allows the depth of the tissue to be read (Krogman 1962). There has been some discussion about the accuracy of data collected from cadaveric tissues (Stephan & Simpson 2008), the affects of post-mortem processes on the soft tissues (Machers & Morris 2005; De Greef *et al.* 2006) and a study by Simpson and Henneberg (2002) indicated that embalming may affect soft tissue thicknesses of a cadaver. Most recent studies have used radiographic means to collect data from living individuals (Kurkcuoglu *et al.* 2011; Stephan & Simpson 2008).

Stephan and Simpson (2008) have revised the published averages for soft tissue thicknesses of the face used in facial approximation. The recent trend is to develop data sets that concentrate on averages for population groups rather than the full range of variation. Some studies (Aulsebrook *et al.* 1996; Kurkcuoglu *et al.* 2011) state that individuals considered obese or not within a normal body weight range were not considered for sampling while in others (Cavanagh 2010; Cavanagh & Steyn 2011) the relevant data on weight were unavailable and as a result underweight and overweight individuals were presumably included in the sample, but their influence on the range of variation is unknown.

A study by Starbuck and Ward (2007) determined that observers frequently perceived reconstructed faces of the same individual, with varying body fat from emaciated to obese, as being reconstructions of different people. They suggested that multiple approximations could be used to overcome these recognition problems caused by normal human variation.

While a population standard tissue thickness is a useful tool, it ignores individual variation which, in theory, could be greater than the variation between the population groups or even between the sexes. Although it is a reasonable assumption that a significant proportion of the variation in facial tissue thicknesses comes from anatomical differences between populations, we do not know how much of normal variation is caused by including the full range of individual obesity or slimness.

1.2. PROBLEM STATEMENT AND AIMS

The aim of this study is to test if facial tissue thickness is due to the amount of sub-cutaneous fat, sex or ancestry group. This was achieved by:

1. Standardisation of measurements from LODOX® images. LODOX® was used in this study due to its low dose of radiation, speed and accessibility.

a) Recording of facial tissue thickness measurements from LODOX® images of a representative sample of cadavers.

b) Recording of physical soft tissue measurements of the same cadavers.

c) Determining if there is a difference between the soft tissue thickness measurements taken from LODOX® Statscan images and the physical tissues through statistical analysis.

2. Comparative LODOX® data from a living sample of volunteers.

a) Developing a set of LODOX® images for measuring facial tissue thicknesses from a volunteer sample.

b) Statistically analyse the soft tissue thicknesses of the volunteer sample to establish where soft tissue thicknesses change as fatness changes.

c) Statistically analyse the soft tissue thicknesses of the volunteer sample to establish where the variation is statistically large between fatness groups, the sexes and ancestry groups.

d) Statistically analyse the soft tissue thicknesses of the volunteer sample to establish the co-variances between fatness groups, the sexes and ancestry groups.

e) Statistically analyse the soft tissue thicknesses of the volunteer sample to establish where the homogeneity of variances between fatness groups, the sexes and ancestry groups is statistically large.

2. LITERATURE REVIEW

2.1. INTRODUCTION

Forensic science is involved with, among others things, the reconstruction of the crime scene and the identification of all involved. This involves the efforts of a number of experts in their fields. There are two basic types of evidence; the biological, the parts of the body; and the peripheral, any artefacts associated with the scene and case (Işcan & Helmer 1993). When skeletal remains are found it is necessary to identify to whom those remains belong. This is the job of the biological anthropologist.

Biological anthropology is the study of the features and structures of the human body and how they vary between people. In particular, the biological anthropologist must pay specific attention to the skeleton and what information can be derived from it (Brues 1958). Forensic anthropology as a sub-discipline of biological anthropology, centres on the analysis of human skeletal remains in the legal context, including facial reconstruction (Işcan & Helmer 1993). Each case is different and even experts may not be successful in providing proof-positive identification of the remains (De Greef *et al.* 2006). It is when all other means of identification have failed that facial reconstruction is attempted.

Depending on the context of the remains and their retrieval, the biological anthropologist must determine first if the remains are human, as the bones of humans and many animals are similar (Brues 1958; Işcan & Steyn 2013), and if the case is forensic, historical or archaeological (Işcan & Steyn 2013). In the case of a suspected identity, the biological anthropologist must verify what if any features exclude the remains (Brues 1958). In other cases there is no idea of a potential identity.

Identification can be encumbered by the state of the remains, whether it is due to predation or the manner of disposal. The hands and feet are the least likely remains to be fully recovered (Brues 1958). They are often left exposed and easily accessible to large and small predators, the small bones and many joints making them easy to sever and transport away from the body. The ribs and skull are the most likely bony elements to be recovered as they are not attractive to predators, and the skull being the most recognisably human bone even to the layman (Brues 1958).

In our own laboratory we often receive only the skull and when enquire as to the location of the discovery site, are informed that the skull was found at the base of a hill. This is often the case when the skull, a larger and heavier bony structure, becomes detached from the body as it decays and rolls down the hill.

Throughout life the skeleton undergoes changes and these changes are related to the overlying soft tissues (Gerasimov 1971). The process of identification starts with an anthropological analysis of the skeletal remains to determine the biological characteristics of the victim or target individual- their age, sex, ancestry, stature and other identifying features such as medical conditions or trauma (Işcan & Helmer 1993; Işcan & Steyn 2013; Prag & Neave 1997). Naturally, the more complete the remains, the more accurate the assessment of these characteristics will be however this is rarely the case (Işcan & Helmer 1993).

Even in the event that only the skull is recovered, there are still a number of aspects of the individual which can be estimated and, when all other means of identification have been exhausted, be of use in facial reconstruction. Other factors may be determined by examination of the post-cranial skeleton, artefacts and even burial context. These are all factors which will influence the tissue thickness standards used and final appearance of the reconstruction (Prag & Neave 1997) which uses set standards of tissue thicknesses determined by age, sex and ancestry.

The study of facial reconstruction is concerned with the examination and measuring of soft tissue thicknesses and the morphological relationship of them with the underlying bony skull (Cavanagh 2010). The interest is to be able to determine and reconstruct, to a recognisable degree, the target individual’s face and features.

2.1.1. THE SKULL AND ITS ROLE IN IDENTIFICATION

The skull is made up of two sets of bones. The eight cranial bones are flat bones that form the cranium, articulating to house and protect the brain. The 14 facial bones, which are irregular bones, that form the facial structures that provide support for the eyes, mouth and nose. The variation in shape and size of these bones plays an important part in establishing the individual face (Van De Graaf 2000) and determining certain biological criteria for use in facial reconstruction. Sex and ancestry are visible from attributes of the skull but only allows for a rough estimate of age (Işcan & Helmer 1993).

Age, sex and ancestry are the three most vital estimations needed when attempting to identify skeletal remains and an attempt to reconstruct the face could not be made without this knowledge. These factors are all significant to the individual's appearance and narrowing the potential identification pool. Ancestry is best determined from the skull, while age and sex are better determined from the postcranial skeleton (Işcan & Helmer 1993).

2.1.1.1. AGE ESTIMATION

The human skeleton passes through a number of growth phases during the first twenty-something years of life. After birth, the skeleton enters a phase of rapid fetal growth and ossification, except at the primary diaphyseal centres of ossification. During the first few years of life, mechanical stresses stimulate the remodelling and ossification of the bones as new and secondary centres of ossification form (Prag & Neave 1997).

The 'biological' age of an individual rarely matches their 'calendrical' age (Gerasimov 1971). It is then necessary to estimate age by assessing all the biological data available, all the signs of aging on the skeleton. It is important to note that age is more easily assessed in juveniles, with the use of dental features and epiphyseal closures, while sex estimation is very difficult before adolescence is reached. The opposite is true for adults. An estimate of age at time of death is one of the most difficult assessments made from the adult skeleton (Işcan & Helmer 1993).

When estimating the age of an individual from the skull, the teeth are of particular importance. There is a sequence of eruption of the deciduous teeth and their loss, which occurs during the first 12 years of life, and the eruption of the permanent teeth which ends around the 25th year (Brues 1958; Işcan & Helmer 1993). The eruption of the M3 or 'Wisdom teeth' is often used to mark maturity, though the timing and even presence of their eruption varies (Işcan & Helmer 1993). Variation does occur with some individuals experiencing early loss and eruption of their teeth, and others who experience no eruption of certain teeth at all.

The wear pattern on the teeth will also indicate age, with the more marked the wear, excluding damage and decay, the greater the age (Brues 1958; Gerasimov 1971).The error is about ten percent in estimating age as there are differences between the sexes, ancestry groups and even individuals; which necessitates that a range of ages be reported (Brues 1958).

After the first 25 years of life the changes to the teeth would have occurred and other means of determining age must be used, though they are less reliable and more prone to subjectivity (Brues 1958; Işcan & Steyn 2013). Other features of the skull used to determine age are the sutures. The sutures fuse over time, completing around the age of sixty years. Again, this is variable and can be greatly delayed or not even occur at all (Brues 1958; Gerasimov 1971). Only a rough age estimate can be made from the skull alone once maturity is reached, with tooth wear and the closure of the sutures being the only indicators of aging (Işcan & Helmer 1993).

After late adolescence, the period in which the ossification centres fuse and active remodelling of the bones occurs, the human skeleton then enters a period in which degenerative processes occur, such as osteoporosis and osteoarthritis, and begin to show signs of stress.

More drastic changes to the skull can be seen with increasing senility, and can be seen in the soft tissues. Tooth loss leads to resorbtion of the surrounding bone and reduction of the masticatory processes, with the loss of jaw strength, muscle mass and atrophy of the mandible (Işcan & Steyn 2013). The jaw becomes more slender, rounder and the chin more prominent. This leads to a downward shift of the upper parts of the face and shrinkage of the maxilla causes the nose point to droop. These skeletal modifications cause changes to the musculature, with for instance the muscles of the cheeks becoming thinner (Gerasimov 1971).

2.1.1.2. SEX ESTIMATION

The sex of an individual is a genetic trait that characterises an individual as either male or female. An individual's ancestry may vary how their skeletal remains express their sex. The traits most effective in estimating sex do not develop until adolescence or puberty is reached, and sex estimation before this is tentative at best. Sex from the adult skull alone can be estimated at between 80- 92% accuracy (şcan & Steyn 2013).

If the remains are accurately sexed, then immediately approximately 50% of the population can be eliminated from the identification pool (Brues 1958). While sexual dimorphism is present to some degree in modern humans, it is not as marked as in our ancestors. Multiple points of sex variation need to be examined and in some cases the lack of marked differences can make estimating sex difficult (Gerasimov 1971).

The accuracy of sex estimation increases with the completeness of the remains and their condition. With the pelvis alone accuracy is around 95%, the skull around 90%, and between 95-100% when the whole skeleton is examined (Prag & Neave 1997).

Biological sex of an individual can be estimated from the skeleton by looking at the prominence, shape and size of certain features of the bones (Prag & Neave 1997). Sex estimation is largely limited to adult remains as the different sex characteristics develop in puberty (Brues 1958; Işcan & Steyn 2013) a consequence of the different sex hormones. The sexual dimorphism of the skull is a result of body size dimorphism and differences in robusticity, and not child-bearing as with the pelvis.

The female skull is rounded, with sharp orbital ridges, small mastoid processes, a vertical forehead and the external occipital protuberance is small compared to the male skull which tends to be larger and have more rugged features to allow for greater muscle attachments. Males have larger supraorbital ridges, mastoid processes, external occipital protuberance. (Prag & Neave 1997). The female mandible is less robust, with little to no gonial flare, a vertical gonial angle and a v-shaped chin, while the male mandible is more robust, with the gonial flare being more pronounced and the chin exhibiting a more square shape (Prag & Neave 1997).

Overall, males tend to have larger muscle attachment sites for larger muscles, with the characteristics being more robust and heavier (Brues 1958; şcan & Steyn 2013) compared to females who tend to have a marked more gracile appearance and smaller cranium (Gerasimov 1971).

Ancestry is a necessary consideration when estimating sex.

2.1.1.3. ANCESTRY ESTIMATION

Traditionally, ancestry assessment in forensic facial reconstruction has followed a typological approach, classifying the appearance and presence of features into separate groups. This has been largely criticised for it does not account for human variation (Morris 2010; şcan & Steyn 2013).

Distinction between the population groups is best made from the skull as almost all the characteristics which can be used to determine ancestry are found on the skull and face, with few characteristics found on the rest of the skeleton (Brues 1958; şcan & Steyn 2013). This already difficult process is compounded by the migration and mixing of population groups in the last century (Brues 1958; şcan & Steyn 2013; Prag & Neave 1997). It is important to remember that, as with all features of the skeleton, these characteristics occur on a continuum and that there are those within population groups who do not exhibit that groups characteristics and may exhibit those of another (Prag & Neave 1997), which is why a number of features must first be considered before a conclusion can be reached.

The assessment of ancestry is mostly performed visually (Hefner 2009), with the shape and prominence of different osteological characteristics more commonly associated with different ancestries being used to estimate the likely ancestry grouping of the individual. Studies by Hefner (2009) and L'Abbe *et al.* (2011) showed that while different characteristics had statistically significant relationships with ancestry they also showed high levels of intra-group variation.

Some characteristics which are of use in estimating ancestry are only found in the soft tissue, such as eye and skin colour (Brues 1958). These are often not present or unreliable due to decomposition of the remains and the colour changes which occur during this process. However, hair can be used to suggest ancestry if recovered in the case of an individual of African ancestry (Brues 1958) or European if red or blond. Other characteristics which would be seen in the soft tissues can be traced back to features on the skull, providing information on not only their position but shape as well (Brues 1958; Işcan & Steyn 2013). And further characteristics are only visible on the skull, such as skull shape and breadth, the prominence of the zygomatic arches and the lower rim of the nasal aperture (Brues 1958; Işcan & Steyn 2013).

2.1.1.4. OTHER CHARACTERISTICS

Further examination of the remains may be needed to determine if there are any individualizing features, which can carry great weight in identifying the remains (Brues 1958). These features would include dental work and tooth loss, as well as signs of surgery and trauma. Even asymmetry of the face can be traced to asymmetry of the skull, and certain features or characteristics which would be seen as true features of the face can be seen on the skull (Gerasimov 1971).

2.2. FACIAL RECONSTRUCTION

In the medico-legal and anthropological scene, the identification of remains is a growing field, with the skull a key clue in supplying a framework from which the unknown individuals appearance, and eventual identification, can be supposed and identified (Işcan & Helmer 1993). The task of identifying the remains of an individual is made difficult by the lack of documentation, witnesses, trauma and the processes of decomposition. A number of methods of identification have been developed over the years, including DNA analysis, fingerprinting, skull photo superimposition and dental records (Cavanagh 2010; Torres Muñoz *et al.* 2011). In the event that no other means has elucidated an identification, then an attempt to reconstruct the target individuals appearance from the skull can be made (Işcan & Helmer 1993).

Facial reconstruction is also known as facial restoration, reproduction, sculpture and approximation (Gatliff 1984; Stephan 2003), and is the attempt to recreate a portrait of the head and face from the skull. This is most commonly done using different two-dimensional (2D) and 3D techniques (Cavanagh 2010) using artists clay or other modelling mastic (Ullrich & Stephan 2011) and, more recently, using virtual computer-based techniques (Cavanagh & Steyn 2011). When applied scientifically, it is the examination and measuring of the soft tissues of the face and how they relate to the skull (Aulsebrook *et al.* 1995).

There are four categories of facial reconstruction used (Aulsebrook *et al.* 1995):

1. The replacing and repositioning of damaged and distorted tissues on the skull;
2. The use of photographic transparencies and drawing in an identikit system;
3. The superimposition technique which uses photographs or video;
4. The 3-dimensional reconstruction of the head and face on the skull

Figure 2.1 Skull with attached soft tissue depth markers at the facial landmarks (şcan & Steyn 2013, pp 364).

It is the fourth category of facial reconstruction which is of interest in this study. To generalise the process, the facial structure and features are constructed over the skull using clay, features such as the eyes, nose, mouth and ears are recreated following anatomically-based guidelines, and other items such as hair, glasses, hats or whatever may have been recovered with the remains can be added to the reconstruction (Machers & Morris 2005).

2.2.1. HISTORY OF FACIAL RECONSTRUCTION

The skull has held a place of interest in many cultures and societies of the world and the urge to know what our past looked like is strong. New discoveries urge us to re-examine theories and classifications which have become commonplace, taken for granted. The idea of facial reconstruction from the skull originated with the interest in the appearance of early humans and our own origins, as well as the appearance of historic figures (e rasimov 19 1 ; şcan & Steyn 2013). The skull has played a part in forensic medicine for over 150 years, as a means to validate the supposed remains of famous historic figures, criminals and the unknown (Iscan & Helmer 1993; Stephan 2011).

It was with the advent of photographic technology that new means of identifying individuals from skulls developed. The method is similar to that using the superimposition of outline drawings of the skull and the deathmask or portrait in corresponding positions (Işcan & Helmer 1993; Stephan 2003). Other methods include the projection of the skull over the drawing, portrait or photograph, then the position adjusted (Işcan & Helmer 1993).

The Italian artist and sculptor Giulio Gaetano Zumbo (1656-1701 CE) was considered a pioneer in the field of sculpting anatomical wax models. His countryman Ercole Lelli (1702-1766 CE) produced wax models of the muscles on human skulls, mostly for teaching purposes (Prag & Neave 1997).

The first attempts at facial reconstruction were by the Jena anatomist Schaaffhausen in 1877 (Gerasimov 1971) , using arbitrarily chosen thicknesses to imitate the facial soft tissues (Fedosyutkin & Nainys 1993), and the reconstruction of a Stone Age woman’s face by Kollman and Buchly in 1898 (Starbuck & Ward 200 ; avanagh 2010; şcan & Steyn 2013). The first Russian attempt to reconstruct the appearance of a person from fossil remains was by Bogdanov in 1882 (Gerasimov 1971).

While other means of facial reconstruction were attempted it was not until 1895 that there was an attempt at a scientific approach. The anatomist, His, attempted to identify the remains of the German composer and musician Johann Sebastian Bach (1685-1750 CE) through facial reconstruction (Prag & Neave 1997). Though there are those who would argue that it was Kollman and Buchly’s attempt at a Stone Age woman that was the first scientifically based reconstruction (Starbuck & Ward 2007; Cavanagh 2010).

His’s work in 1895 was the first attempt at a scientifically controlled reconstruction. He collected data on soft tissue thicknesses from twenty-four male and four female cadavers (Gatliff 1984) by measuring the tissue thickness measurements at nine midline and six lateral (a total of twenty-one) anatomical landmarks using what is now referred to as the needle puncture method: a sharp needle is used to pierce the soft tissue until reaching bone while a rubber stopper marks the level of the skin on the needle when the needle is removed from the tissue. The distance between the needle tip and the stopper is then measured (Prag & Neave 1997). His used the data to model flesh on a cast of the skull, using the anatomical landmarks to identify the depth of the soft tissue at those points.

The work was further confirmed by comparison between the skull and portraits of the composer painted during his lifetime and in the mid-1920’s by the British biometric school of artists in London (Prag & Neave 1997). A contemporary of His, Welcker, an artist, used two-dimensional superimposition techniques along with his own data on soft tissue thickness to correctly identify the skull of Schiller (1795-1805 CE), a German playwright and poet (Prag & Neave 1997) and later compared the self-portrait of the artist Raphael to what was thought to be his skull to demonstrate its authenticity (Gerasimov 1971). He also identified other historical figures such as Dante and Kant (Cavanagh 2010).

Building on the existing knowledge of His and Welcker, two Swiss men Kollman, an anatomist, and Buchly, a sculptor, furthered the study of soft tissue thicknesses (Prag & Neave 1997; Cavanagh 2010). Kollman measured the soft tissue of women from the Auvergne region in France and proposed a technical procedure for reconstruction of faces from skulls. This technique was then added to by the expertise of Buchly to construct the nose, mouth, ears and hair (Gerasimov 1971). The measurements of 45 male and eight female cadavers were added by Kollman and Buchly in 1898 to His and Welcker's research, with a large age range of 1 to 2 years of age and described as being of moderate nutrition levels (Gatliff 1984; Prag & Neave 1997). It must be noted that these measurements were not taken from live subjects and post-mortem changes may have affected these measurements, even though they were taken under 24 hours after death (Gatliff 1984).

Later, there were many attempts by anatomists to recreate the likenesses of ancestral humans in the early 20th century; such as Solger (1910) attempted the reconstruction of an adult neanderthal from studying the fossil skull of a youth from the Le Moustier cave, Martin and Eggeling (1913) attempted the reconstruction of two different heads from the same skull from La Chapelle-aux Saints, and Masquet and Rutot attempted a series of portraits of ancestral humans (Gerasimov 1971; Prag & Neave 1997). Of note is the reconstruction by Boules of only the facial musculature without skin (Gerasimov 1971).

The remains of Bach, Kant, Haydn and others were identified by the anatomist Geiss who compared the skulls with their portraits. A German sculptor Sefner reconstructed the face from the skull Geiss identified as from Bach, creating an agreeable likeness of the composer. He went on to study if, given a skull, the visage of the person can be reconstructed. He took casts of the Bach skull and attempted to reconstruct the face of Handel, which could be done but only by ignoring the shape and size of the skull, resulting in tissues merging with bone or being abnormally thick in places. The British biometrical school went on to prove the work of Welcker and Geiss with a newly developed technique of comparing skulls and portraits. Most of these early methods made use of the simplified superimposition of photographs over skulls (Gerasimov 1971).

Eggeling studied the variations of the soft tissue thicknesses of the head and face. He performed an experiment where he took casts of the face of a recently dead man, measured the soft tissue thicknesses at various craniometric points so the soft tissue could be modelled. Casts were made of the skull once it was defleshed. The casts and soft tissue data were given to sculptors who produced reproductions with no likeness to each other. This experiment led to many anatomists to conclude that an individualised reconstruction could not be recreated from the skull. This led to the majority of anatomists and anthropologists to consider facial reconstructions of both ancient man and more recent dead to be inauthentic. Today, it is considered that the sculptors were at fault, not taking the shape, contours of the skull into consideration during their reconstruction (Gerasimov 1971).

The high amount of variation between the different reconstructions, even of the same skull, led to severe criticism and many doubts as to the authenticity of the theory that an individual’s likeness can be reconstructed from the skull (e rasimov 19 1 ; şcan & Steyn 2013). Surely, if they were using the same skull to direct their reconstructions then the reconstructions should be similar?

The work of Gerasimov was one of first to attempt reconstruction on a physiognomic basis (Işcan & Helmer 1993) and, despite the criticism of facial reconstruction as a practice, is of considered the founding work in present anatomically based facial reconstruction methods (Ullrich & Stephan 2011).

Gerasimov, a Russian palaeontologist and anthropologist, took an interest in facial reconstruction and undertook years of research to determine if it was possible to use only the skull and the information it could provide to accurately reconstruct a likeness of the individual during life (Gerasimov 1971). His work brought attention back to the process and the development of better methodologies of facial reconstruction. His method became synonymous with anatomical reconstructions and known as the ‘Russian Method’ (rag & e ave 199 ; llri ch & Stephan 2011; şcan & Steyn 2013).

He studied the early measurements of Kollman and how the morphological features of the skull could be used to model individual features. He observed from his own studies and other literature that the tissue of the face varied in different places. He noted that the landmarks of the profile lay closest to the bone with the least variation and used those as fixed points. His early reconstructions were admittedly flawed and over a period of months he attempted to refine his methods and materials. In 1925 he received a skull which, after assessment, he determined to be of a young female. The reconstruction (Fig. 2.2), he considered, to be that of a very good-looking girl and a true portrait (Gerasimov 1971)

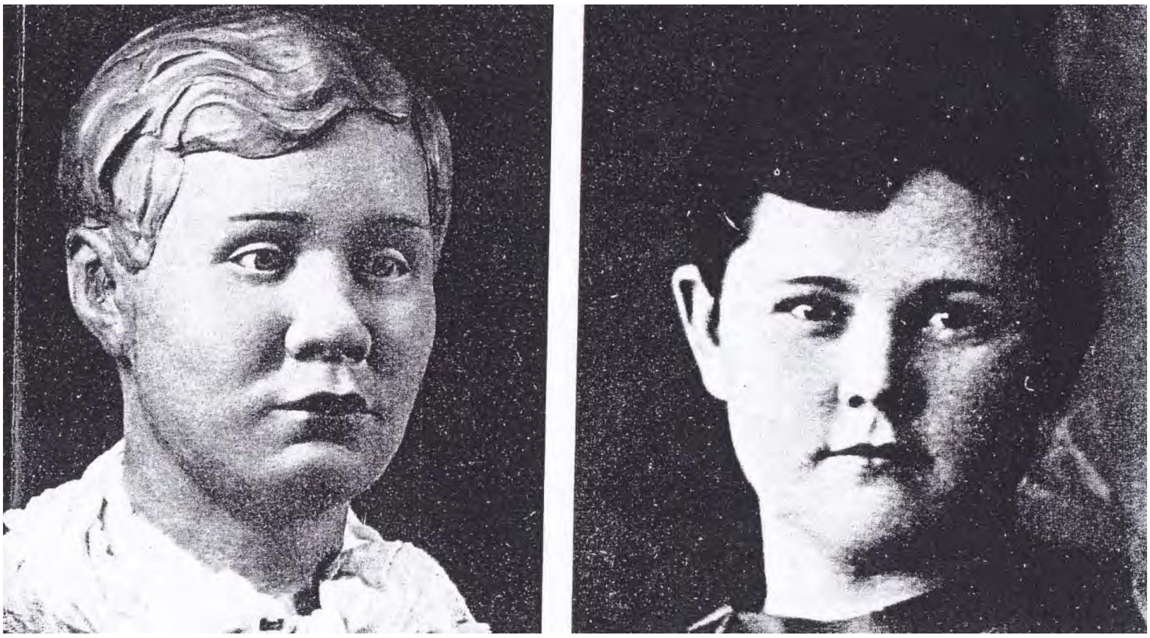


Figure 2.2 The reconstruction used to identify remains as those of Valentina Kosova. The skull was found without the mandible and the photograph taken six years before the woman disappeared (Gerasimov 1971).

Later, he performed an experiment with 3 skulls where they were reconstructed using anthropological information assessed from the skulls themselves and not the skulls' own records. The reconstructions were then assessed for their resemblance to their recorded ancestry group and were found to show that, with consideration of the skulls features, likenesses to the targets individual's ancestry could be constructed. It was also found that the targets age was represented in the reconstruction. This was seen as convincing argument that reconstructions from skulls could accurately resemble the ancestry and likeness of a living person (Gerasimov 1971).

Gerasimov later reconstructed the face of a French athlete Loustalot. The reconstruction was compared with the individual's death-mask but they were found to be very different, with the lower face of the mask being swollen and broader than the reconstruction. Initially, this experiment was deemed a failure, however, later chance and investigation showed that not only did the athlete have facial hair but the mask had been taken of a decay distorted face (Gerasimov 1971). The swollen and distorted face of the mask would not have matched the reconstruction which had been of Loustalot in life.

These experiments helped Gerasimov to refine his technique and establish a method to confirm his theory that the face can be modelled accurately from the skull. A large scale test was necessary, especially if his methods were to be used in the forensic arena. In a Moscow mortuary, the chosen target heads were photographed and then defleshed. The skulls were then sent to Leningrad where Gerasimov performed blind reconstructions, having no contact with the mortuary staff or having seen the photographs. The reconstructions were presented and found; even with representation of both sexes, various ages and multiple ancestry groups; that the reconstructions bore great likenesses to their matched photographs and could be identified (Gerasimov 1971).

He went on to reconstruct models of known individuals, those of people unknown to him but with photographic record of their appearance to compare against the reconstructions from their known remains. Gerasimov's work included the facial reconstructions of over 200 people, including historical figures such as Yuraslav the Wise, Ivan the Terrible, Friedrich Schiller, Rudaki and Tamerlane (Gerasimov 1971; Prag & Neave 1997; Cavanagh 2010).

In America, facial reconstruction started to be used around 1918 in forensic cases, it became popular due to the work of Krogman (İşcan & Steyn 2013). His work became known as the 'American Method', and unlike Gerasimov's method, used mostly tissue depth measurements to determine the face.

The study of facial reconstruction continued and became popular practice by the early 20th century in many anthropological fields (Cavanagh 2010), with a greater focus on research and standardisation. A series of soft tissue thickness databases have been published since those first attempts, narrowing down the variation between the ages, sexes and ancestry groups.

This included the data set published by Rhine and Campbell for Americans of African ancestry in 1980, which they compared with data from European and Japanese studies. They published data for American whites in 1982 and revised their data to establish tissue thicknesses for each of the sexes in each of the ancestral groups. Of interest was the inclusion of a subdivision by one of three body weight groups: emaciated, normal and obese (Gatliff 1984).

2.2.2. METHODS OF FACIAL RECONSTRUCTION

Facial reconstruction uses a variety of methods, from 3D portraits to digital animations (Wilkinson 2010). There are 3 main methods or theoretical frameworks in use (Stephan 200 ; şcan & Steyn 2013):

1. The Russian method, also known as the morphoscopic or erasimov's technique.
2. The American method, also known as the morphometric or atliff's technique.
3. And the Manchester or British method, also known as the combination method, developed by Neave.

Though, it can be argued that both the Russian and American methods took into account tissue thickness measurements and craniofacial anatomy, respectively, when developing their techniques and that there may be no true separation of methods (şcan & Steyn 2013).

The basic tenet of all facial reconstruction methods is to reconstruct the face on a cast of the skull and never on the original itself. Prag and Neave (1997) outline the three reasons:

1. Forensic specimens may require further examination before the reconstruction process is complete, so it needs to be readily available.
2. Archaeological or historical specimens are often too fragile for much handling and the practice is not to subject any ancient material to processes which may cause damage.

3. A damaged or fragile specimen is often unable to support the weight of a reconstruction.

The idea being that a damaged cast is replaceable, but a damaged specimen is not. A properly performed skull cast will retain the needed information on the muscle attachments, trauma, age, sex, ancestry and other surface details which may be used in the reconstruction.

Alginate is a good impression material for casting (Taylor 1998) and is commonly the material used for moulds as it is flexible and fast setting but still fragile. This means that the mould is likely to break before the specimen, helping to prevent any damage to it. A 'split-mould' technique is commonly used to create a mould which is designed to split around the specimen for easy removal. Plaster or plastic is used to create the cast, by filling one half of the mould, sealing it to the other and continually rotating the complete mould to allow an even coating of the cast material. The cast is then checked for blemishes and measured against the original specimen for accuracy (Prag & Neave 1997).

Before reconstruction can commence, the mandible must be fixed to the skull by affixing the condyle of the ramus into the glenoid fossa of the temporal bone (Gatliff 1984; Taylor 1998). It is positioned so the teeth are in centric occlusion, and for those remains which are edentulous or lack the majority of the teeth the average measurements of the dimensions of the mouth are used to position the mandible with the skull (Taylor 1998). The skull is then most often fixed in the Frankfort horizontal on a stand (Gatliff 1984). A number of variables are important in reconstruction and so there are different sets of tissue thickness tables for the sexes, various population groups, and standard of health or fatness. Once a set is selected, the required number of anatomical points, or landmarks, for that set are marked on the cast (Prag & Neave 1997).

The key to the success of a method is if the individual viewing the reconstruction can make a suitable comparison with the target individual (Işcan & Helmer 1993). If the information is available, features such as hairstyle, jewellery and age can be added to aid in recognition. This differs depending on the context of the reconstruction. Archaeological reconstructions are meant as a 3dimensional portrait of the research while a forensic reconstruction is meant to insight recognition and identification, so any features which may be speculative or distracting may not be included in the forensic reconstruction (Prag & Neave 1997).

2.2.2.1. THE RUSSIAN METHOD

This method of facial reconstruction is reliant on the facial anatomy and uses the indicators of muscle insertions, their robusticity and the target individuals ancestry on the skull as a guide (İşcan & Steyn 2013). It is described as being performed by reconstructing each muscle of the face individually and then overlaying a ‘skin’ layer. The reconstruction occurs in 2 phases. The first phase is the modelling of the head and neck, and the second phase is the modelling of the face itself (Gerasimov 1971). It is a primarily qualitative method that relies on the practitioner’s knowledge of facial anatomy and skull morphology. However, this reliance and what little literature Gerasimov published on his method makes the technique very difficult to repeat (Ullrich & Stephan 2011).

The muscles of mastication and the neck are first modelled to shape the face. They are able to be accurately modelled as their size and shape can be determined from the skull (Gerasimov 1971). The second phase requires much experience and specialized training, especially in relation to the more difficult features to reconstruct such as the nose, mouth, ears and eyes (Gerasimov 1971) however difficulty has been reported in following the method described in the literature (Ullrich & Stephan 2011).

Experience in practical application forms the basis of Gerasimov’s method which emphasises the necessity of skill, a methodological approach and anatomical knowledge when approaching a reconstruction as the best means to minimize error (Fedosyutkin & Nainys 1993). Compared to the American and Manchester methods, the Russian method is a primarily qualitative one (Ullrich & Stephan 2011).

2.2.2.2. THE AMERICAN METHOD

This method is described as relying more heavily on soft tissue thickness measurements (şcan & Steyn 2013), using the databases specific to the target individuals sex, age and ancestry. Rubber cylinders are measured and cut into the desired lengths needed to mark the tissue depth at the landmarks. These tissue thickness measurements consist of the full tissue depth, including the muscle, fat and skin. The markers are attached to the skull at the landmarks. The open spaces are filled in and contoured to follow the marker thickness measurements, forming the shape of the face (Gatliff 1984; şcan & Steyn 2013). The shape and size of the facial features; the nose, ears, mouth and eyes; are carefully estimated from the skull as they create the individualization of the face (Gatliff 1984).

Figure 2.3 An example of a reconstruction performed using the American technique (şcan & Steyn 2013, pp 364).

The teeth are used to estimate the shape of the mouth, following 3D:

- The tissue thickness of the upper lip margin
- The vertical thickness of the lips is measured as the space between the gum lines
- Two lines radiating out from the junction of the canine and first premolar determine the mouth width

The lips are curved over the teeth and the parting line determined by a horizontal line from each corner of the lips. Sculpting striations and curvature give the lips a realistic appearance (Gatliff 1984).

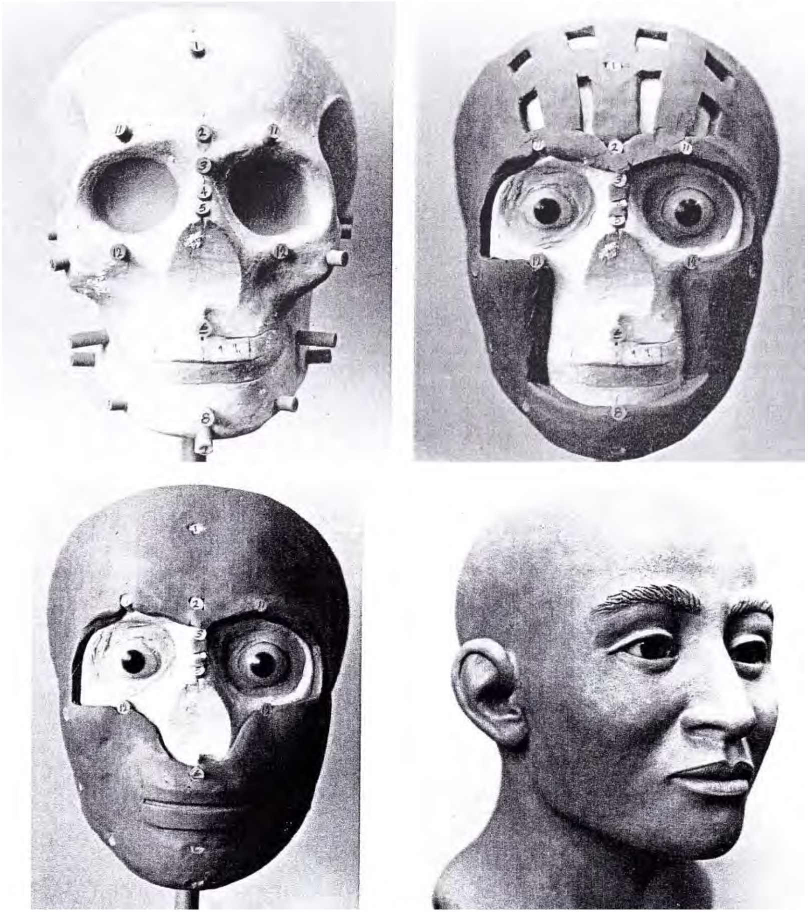


Figure 2.4 Sequential images of a reconstruction performed by Gatliff. Note how the landmark markers are placed, the chosen modelling mastic then filling in the spaces between them (Gatliff 1984, pp 330-331).

The eye is located in the centre of the orbit with the cornea tangentially to a line drawn from the inferior and superior orbital margins. Eyelids are sculpted over the ball of the eye, following the natural contours it creates (Gatliff 1984).

The nose is estimated by measuring the bony nasal aperture at its furthest points and increasing them by 10 mm or 16 mm for whites and Africans, respectively. The projection of the nose is estimated to be three times the length of the nasal spine. The slope and shape of the nasal tip is determined by the size and curve of the nasal spine (Gatliff 1984).

The ‘rule of thumb’ when determining the ears is that they should be equal to the nose in length. The ear is constructed from a conch shape and attached at approximately 15 degrees, the external auditory meatus at the top of the tragus (Gatliff 1984).

2.2.2.3. THE MANCHESTER METHOD

This method of facial reconstruction is a combination of the Russian and American techniques and relies on a knowledge of both the craniofacial anatomy and soft tissue thickness measurements (şcan & Steyn 2013). It is described as being performed by reconstructing each muscle of the face individually and adding the ‘skin’ layer using tissue depth measurements (Wilkinson 2010).

Pegs of varying length per anatomical landmark, determined from the chosen tissue thickness table, are attached and used to mark the extent of the reconstructed face. Separate pegs or pins are used to mark the medial and lateral canthus of the eyes and to provide some scaffolding for constructing the nose (Prag & Neave 1997).

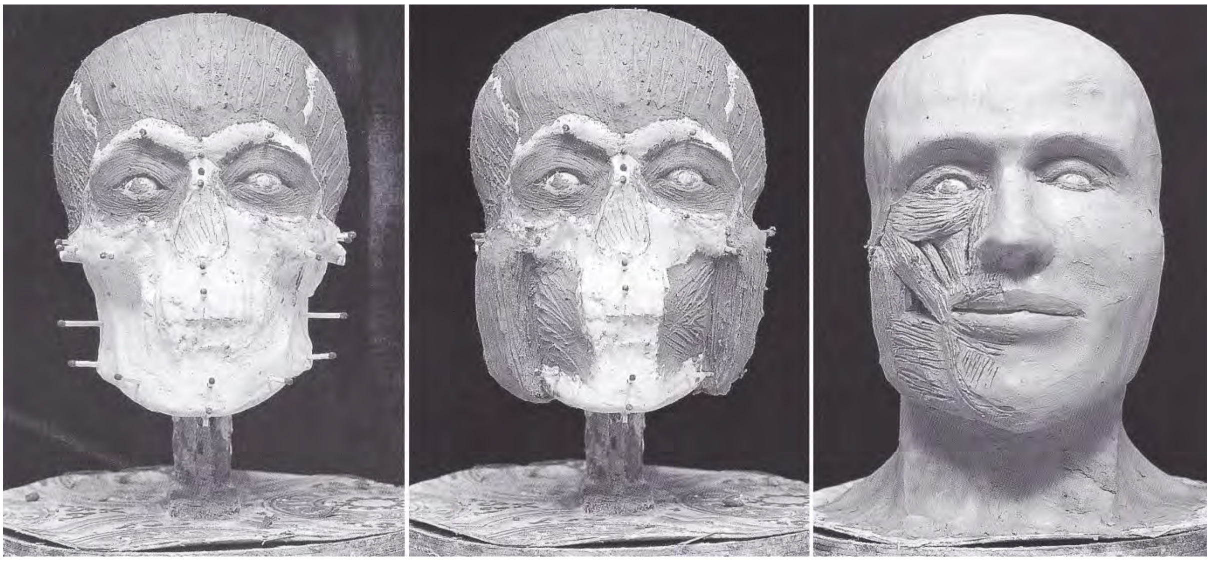


Figure 2.5 Reconstruction showing the transition of the face on the skull cast (Taylor 1998, pp 181-183).

Using clay, the soft tissue and muscles of the face are built up. The muscle insertions are used to determine the bulk and prominence of the muscles, which will determine the shape of the face. It is important to note that the dimensions of the individual’s muscles are not as important as the tissue depth and directionality (Prag & Neave 1997), though the practitioner needs to be aware of the subtle differences of the muscle attachment sites, which, in a reconstruction, can produce very different face shapes, contours and proportions (Wilkinson 2010).

The soft tissues are built up following the anatomy of the face. The initial muscles built are the temporalis, masseter, buccanator and occipital frontalis, followed by the orbicularis oris and orbicularis oculi which start to form shape of the face (Prag & Neave 1997; Taylor 1998). The neck is built in bulk, highlighting the sternocleidomastoid muscles and manubrial notch. The nose and lips are usually constructed at this stage so the rest of the muscles can be constructed around them. Age, sex, ancestry and occlusal patterning will affect the form of the soft tissue features (Taylor 1998). The other muscles follow and in areas where the structures may be too complex to realistically reconstruct, an idealised model is constructed instead (Prag & Neave 1997).

The borders of the mouth are determined by the outer borders of the canines or the inner borders of the iris (Prag & Neave 1997). The philtrum of the lip is affected by the length of the lip, the lip support given by the teeth and the shape of the base of the nose (Taylor 1998).

Additional muscles of facial expression are then added, taking into account their relative delicacy and how they would be surrounded by other tissues in the living individual (Prag & Neave 1997). There should be little to no interpretation at this stage needed if all the facial structures are modelled following strict anatomical guidelines (Wilkinson 2010).

A rough approximation of the nose can be determined by taking a tangent line from the distal end of the nasal bone to where it bisects a line projected from the anterior nasal spine or acanthion. The slant of the eyes is determined in relation to the lacrimal fossa and the outer tubercle of the inner orbit of the eye socket (Prag & Neave 1997).

The shape and size of the muscles are built up over the angles and planes of the skull cast, eventually being over-layed by strips of clay to follow the contours of the underlying clay construct (Prag & Neave 1997). Error can be expected as individual muscle variation may not be visible on the skull, such as muscle bifurcation, duplication or even absence (Wilkinson 2010). At all time the peg markers are kept in mind so that the constructed tissue remains within the tissue measurements, representing the average tissue thickness measurements at those anatomical landmarks (Prag &Neave 1997; Wilkinson 2010) and where there is conflict between the indicated averages and the anatomy, they are removed (Wilkinson 2010).

The use of strips of clay to recreate the subcutaneous tissues, is meant to minimised the influence and subjectivity of the artist on the final product (Prag & Neave 1997; Wilkinson 2010). Other features of the face are added, with the eyebrows, nose, mouth and ears are largely subject to the experience and anatomical knowledge of the artist.

2.2.2.4. DIGITAL METHODS

With the use of radiographic and magnetic resonance imaging techniques, more objective and reproducible techniques are now available (Taylor 1998). In the past manual methods of facial reconstruction were the norm with skulls being cast and clay or mastic modelled. With the increasing sophistication of computer technologies and imaging software, virtual facial reconstruction hardware and software are being developed to assist in the process and allow for the creation of virtual reconstruction models instead of clay ones (Decker *et al.* 2013).

Manual clay modelling methods can take hundreds of hours and multiple reconstructions are not common (Kähler *et al.* 2003). New virtual methods can decrease that time to hours and multiple reconstructions of varying shape, size and features can be quickly modelled. Virtual methods are more rapid and do not require a high level of anatomical knowledge (Kähler *et al.* 2003), with different software packages allowing for a greater variation in the reconstructions produced (Decker at al. 2013). Additionally, the underlying muscles can be animated to give the reconstruction different expressions, as opposed to the typically neutral and not lifelike expression favoured in manual reconstruction (Kähler *et al.* 2003).

Both manual and virtual methods rely on tight shape relationships between the skull and soft tissue (Kähler *et al.* 2003). The same initial processes are followed in virtual as in manual reconstruction methods: an anthropological assessment is performed, the mandible aligned with the skull and a cast created for the reconstruction base.

Virtual modelling, however, only requires a digital ‘cast’ of the skull which is taken by a contact-free, 3D scan; the files of which can be transported instead of the physical skull (Decker *et al.* 2013). This limits the potential damage to the skull from transportation and manual casting methods. There are limitations in virtual facial reconstruction as it is set to model using averages and can struggle to adjust for and accurately predict the effect of skull deformities on the soft tissues. However, while there can be difficulty in scanning the finer structures of the skull, such as the nasal spine, it can easily model them without the risk of damage to them (Kähler *et al.* 2003).

These new methods of 3D reconstruction allow for the computer-assisted reconstruction of skulls and bones that have been damaged or crushed, particularly fossils which are too fragile for handling or recovered in pieces. They are able to separate out the different pieces and reconstruct them without having to perform potentially destructive operations (Zollikofer 1998).

While facial reconstruction is a limited method of identification used only when more reliable methods have failed, using computer software the reconstruction can be altered and adjusted after the reconstruction is finished at a faster and less destructive manner than with manual methods (Taylor 1998).

It is now possible to perform a complete reconstruction digitally. Computerised facial reconstruction does produce repeatable and more standardised reconstructions but they are now found to be as realistic or lifelike as manual reconstructions (Kähler *et al.* 2003; şcan & Steyn 2013).

2.2.3. NEED FOR BETTER METHODS OF FACIAL RECONSTRUCTION AS A MEANS OF IDENTIFICATION

Immigration and emigration rates, in large regions of varying climatic and population density impacts, further affect the ability of those involved in identifying the remains. (Fedosyutkin & Nainys 1993). There are millions of reported cases of missing individuals around the globe, from armed conflicts and human rights abuses, with thousands missing every year due to disasters, organised crime, violence and other means (International Commission on Missing Individuals 2013). The World Disasters report released in 2012 reported that over 100 000 people had been killed between 2000 and 2012 each year with an unknown number still missing, and it is believed that there are over 72 million migrants, displaced peoples and refugees. Their position puts them at a higher level of risk with the disruption of their protective social networks and leaves them open to becoming victims of exploitation and violence.

The number of missing and unidentified people is ever increasing and in 2010 the Fast and Efficient International Disaster Victim Identification (FASTID) project was launched. An INTERPOL led project, its goal is to assist in the identification of remains from disasters and every-day policing efforts on an international scale, by creation of the Missing Individuals and Unidentified Bodies (MPUB) database (The Fast and Efficient International Disaster Victim IDentification, Database of missing persons and unidentified bodies.).

The Missing Children South Africa report stated that between May of 2011 and April 2012, 540 adults and children were reported missing. Of which, 113 were not found. They reported 670 people missing, of which 152 were not found, between December 2012 to November 2013.

While advances in science technologies allow us to better locate and identify the missing there is still more to be done. Facial reconstruction can play a role in identifying remains, not only from crime, but also from disasters and human rights abuses. By better knowing and understanding the variation between the sexes and population groups of body fat and facial fatness, practitioners can create better reconstructions and provide better means of recognition of the unknown individuals.

2.2.4. CHALLENGES OF FACIAL RECONSTRUCTION AND ITS METHODS

Facial reconstruction or identification is the process whereby the face is rebuilt over the skull in an attempt to reproduce a likeness of the person during life, with the purpose of promoting their positive identification (Stephan *et al.* 2003) but, as a means of post-mortem identification, it is challenging and poses some problems (Kähler *et al.* 2003).

There are weaknesses in the currently used field data (Decker *et al.* 2013) and disagreement between practitioners of the accuracy and reliability of the different methods (Stephan 2003; and Wilkinson 2010). And while it has been studied extensively there are still areas that lack comprehensive study (Cavanagh 2010). To improve current methods of facial reconstruction we must first be aware of what the problems and weaknesses are and approach them scientifically. The literature brings up a number of issues consistently.

2.2.4.1. THE CORRECT TERM TO DECRIBE THE PRACTICE

The term facial reconstruction has been used in this study as it is the most widely used and most recognisable. It is acknowledged that there are problems with this term and that other such as facial approximation and facial reproduction are also applicable.

The term facial reconstruction is also used for other practices, such as facial surgery, and it implies the reassembling of existing parts, a scientific exactness and finality of the product, which it cannot have as 100% accuracy is not possible (Stephan 2003; Stephan 2011). The term facial "reconstruction" is still being used in paleoanthropology despite elemental flaws in this application and most lay individuals still appear to be of the misleading opinion that facial "reconstruction" does actually result in visages that are recognizable as the person to whom the skull belonged, despite the variation in reported success rates and questions as to whether success is due to the accuracy of the reconstruction or other factors (Stephan 2003).

2.2.4.2.RELIANCE ON PRACTITIONERS EXPERIENCE AND THEIR ABILITY TO MINIMISE THEIR OWN SUBJECTIVITY

There has been countless debate as to the accuracy of facial reconstruction, artistic license, scientific basis, with varying success being reported. Some have argued that the reported successes have more to do with the use of media and public recognition, rather than the accuracy of the reconstruction itself. Stephan (2009) reported that some practitioners may update their reconstructions once an identification is made; changing the hair style, eyebrow shape and eye colour; which would then be displayed to demonstrate the reconstructions accuracy. Wilkinson (2004 as reported in Iscan & Steyn 2013) reported that erasimov’s method claimed to have a success rate of 100%, while the American method claimed a 5 success rate and the British method a 5 success rate (şcan & Steyn 2013).

Judging success in facial reconstruction is subjective, with blind studies being ethically difficult (Wilkinson 2010; şcan & Steyn 2013). There are a number of methods used to assess accuracy of facial reconstructions such as face pool assessments, resemblance ratings, and morphometric comparisons (Wilkinson 2010). While there are no set guidelines to test accuracy, there are two favoured tests often used. The first uses face arrays or face pools, where recognition is attempted from a number of different images of different people. This is done using unfamiliar assessors, people unfamiliar with the target individual, and familiar assessors, people familiar with the target individual. The other uses resemblance rating tests, where assessors score the resemblance of the reconstruction to the target individual (şcan & Steyn 2013).

Stephan (2009) found that resemblance ratings were not a good method to test accuracy of reconstructions as there were similar results for the target and non-target individuals, providing inconsistent results.

Decker *et al.* (2013) compared the most commonly used methods of facial reconstruction in manual and virtual methods of a known living individual using a morphometric comparison test. The manual practitioners were provided with casts and the virtual practitioners with the virtual scans, and all were provided with the anthropological assessment. The reconstructions were scanned and compared with a scan of the target individual. Their results showed a wide range of variation between the commonly used methods.

Accuracy ranged between 61-76% with all reconstructions underestimating the upper lip, midline, Glabella, mental regions and chin region. The largest inaccuracies were in the shape of the chin, the shape and orientation of the eyes, the length and angle of the nose and mouth width. There was a range of inaccuracy of the Gonion region, both under and overestimation. They determined that the variation is likely due to the different soft tissue data sets used (Decker *et al.* 2013).

While facial reconstruction has assisted in generating tentative identifications and practitioners report (variable) success (Stephan 2003; Wilkinson 2010; Decker *et al.*

2013), we must also consider if the purpose of facial reconstruction is being properly served or if other factors (such as the context given to the reported reconstruction, media attention, the investigative efforts of the authorities) are being attributed to the recognition of the reconstruction (Stephan & Henneberg 2001; Stephan 2003; Wilkinson 2010).

Stephan and Henneberg (2001) tested the ability of facial reconstructions using four standard techniques to determine if they “are sufficiently accurate to produce correct identities of target individuals above chance”. They asked participants to identify the reconstructed individual from a pool of photographs. Their results showed that only one of the 16 reconstructions was successfully identified above chance levels and therefore concluded that it is rare for facial reconstructions “to be sufficiently accurate to allow identification of a target individual above chance” and that it is not useful in excluding individuals to whom the reconstructed remains may not belong to.

They (Stephan & Henneberg 2001) also questioned previous comparison studies where the reconstruction was compared to the target individual for similarity. Such testing, they argue, does not consider the reconstructions similarity to non-target individuals and if the target individual can be identified from a pool of subjects.

They reiterated the idea that facial reconstruction should only be used as a final recourse when all other means of identifying a victim have failed and even then with caution.

We must also consider the subjectivity of the practitioner when reporting their successes.

In a study by Wilkinson (2010), she looked at issues of artistic licence and practitioner subjectivity. She looked at the techniques used and concluded that the majority of facial morphology in facial reconstruction can be scientifically predicted, though this accuracy decreases with the targets age. Faces have a similar structure, though some muscles may vary in size, shape and even position which can produce very different face shapes, contours and proportions in a reconstruction. Not all muscles attach directly onto the skull and error can be expected as anomalies may not be visible on the bone. A facial reconstruction practitioner needs to be aware of these possible differences and how to interpret them should they be indicated on the muscle attachment sites of the skull (Wilkinson 2010).

Again, the features with the highest levels of inaccuracy are the nose, eyes, mouth and ears (Gerasimov 1971; Stephan 2003; Machers 2005; Wilkinson 2010; Cavanagh & Steyn 2011; Decker *et al.* 2013). However, if modelling is done following the strict anatomical guidelines the results should be reliable and reproducible, reducing the subjectivity of the reconstruction (Wilkinson 2010).

Features such as skin and eye colour are the most difficult to estimate even when there is some information available to the practitioner. Their presentation on the remains will have changed due to the processes of decompositions and their recovery context (Simpson & Henneberg 2002; Machers & Morris 2005; De Greef *et al.* 2006; Wilkinson 2010). There is a huge range of colours and styles within any group and this may have a significant impact on recognition (Wilkinson 2010).

The function of a reconstruction is to reproduce a positive reconstruction, a reconstruction that is positively identified as the target individual, of the unknown individual and forensic case reports do not conclusively prove that current facial reconstruction methods are in fact successful in their function. It is justifiable in a forensic case that every attempt be made to identify a victim, even methods which are not totally reliable or fully tested, as it takes only one person to believe they recognise a reconstruction to lead to a tentative identification (Stephan & Henneberg, 2001; Stephan 2003). Yet, we must not then make the mistake of assuming that success in one case will mean success in others. The variability in reported success rates for different reconstruction methods indicates that we should consider the results of forensic cases and reconstruction with some caution before determining their success (Stephan & Henneberg, 2001; Stephan 2003).

2.2.4.3.LACK OF STANDARDIZATION IN THE COLLECTION AND ANALYSIS OF DATA AND METHODS

Numerous studies have published tissue depths for different populations. The standard soft tissue thickness measurement methods and landmarks have changed throughout the history of facial reconstruction and continue to be modified and refined (Cavanagh 2010).

The first studies used the needle puncture or needle probe (whereby a blackened needle was inserted into the flesh and, when withdrawn, the clean length was measured) method (Cavanagh 2010). The method is still used today (Tedeschi-Oliviera *et al.* 2009) as it is cheap, simple to use, does not require live subjects that are capable of movement, and there is no radiation exposure (Domaracki & Stephan 2006; Dong *et al.* 2012). However, the method has been criticised for its use of cadavers since dead tissue undergoes distortion due to post-mortem processes and embalming (Simpson & Henneberg 2002; Sven 2005; De Greef *et al.* 200 ; Wilkinson 2010; şcan & Steyn 2013) and the determination of landmarks by palpitating the flesh is difficult (Cavanagh 2010).

With cadaver studies becoming more undesirable, there has been shift to other methods for measuring soft tissue thicknesses. With the advances in imaging technologies more recent studies have used radiographic methods to determine tissue depths (şcan & Steyn 2013). Unlike with the needle puncture methods, radiographs allow the use of living participants, with the measurements taken in different positions, upright, and without the effects of gravity (Stephan 2009), while measurements taken from images have been shown to be accurate or of negligible error (Aulsebrook *et al.* 1996; Dong *et al.* 2012).

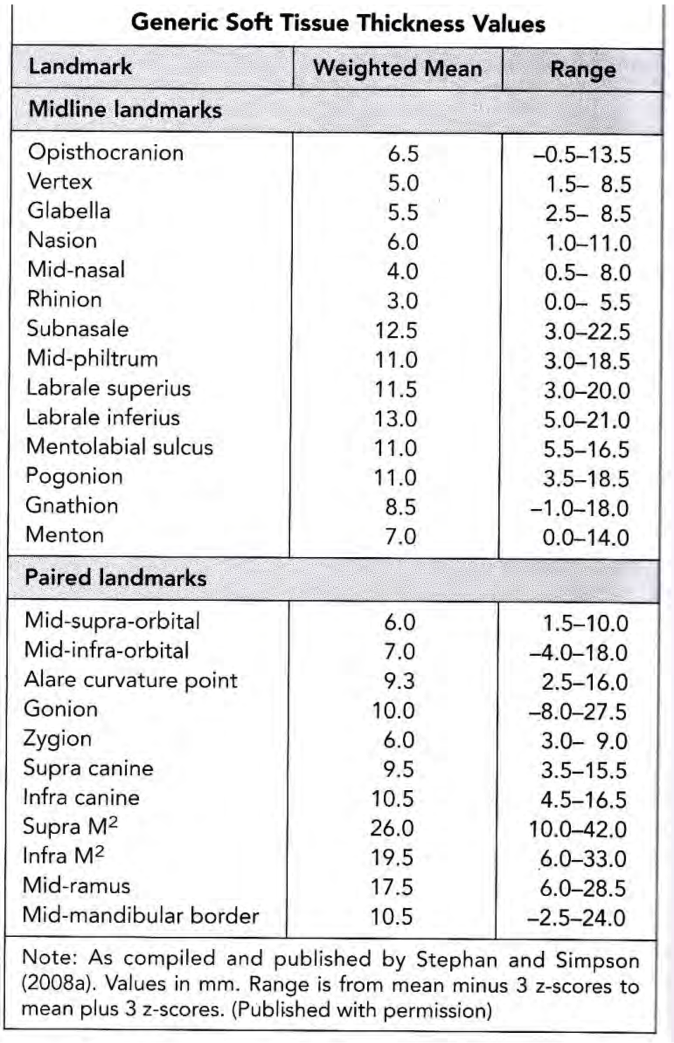
Ultrasound is a considerably popular method (Aulsebrook *et al.* 1996; De Greef *et al.* 2006), as there is no concern over radiation and measurements can be taken directly from living individuals. However, the equipment is expensive and the use of the ultrasound wand, pressed against the skin, can lead to compression of the tissues being measured (şcan & Steyn 2013).

More recently, MRI (Chen *et al.* 2011), LODOX Statscan® (Machers & Morris 2005), CT (Cavanagh & Steyn 2011; Hwang *et al.* 2012; Panenková *et al.* 2012; Guyomarc'h *et al.* 2013) and cephalometric X-ray (Aulsebrook *et al.* 1996; Stephan *et al.* 2003; Utsuno *et al.* 2005; Kurkcuoglu *et al.* 2011) images have been used. This method provides good resolution images of living individuals that can be stored electronically for repeated access.

They do present problems in their expense and higher radiation exposure to the individual, leading the majority of facial reconstruction studies using these methods to be done using images from trauma patients who need to undergo scanning. Such trauma may lead to distortion of the measurements due to swelling and artefact presence (şcan & Steyn 2013). There is also the issue of image distortion to consider (See Chapter 3.2.2.2).

Stephan and Simpson (2008) found there was a wide range of variation in the soft tissue depth measurements from different methods reported, irrespective whether the measurements were from cadavers or living individuals, and concluded no method of measuring soft tissue depths was significantly better. They also note no clear trends at the most frequently used landmarks, despite a global increase in body mass. They pooled all published data in an attempt to overcome these differences in measurements and produced a generic soft tissue thickness value table (see table 2.1) (Stephan & Simpson 2008; şcan & Steyn 2013).

The literature tends to separate the methods used to produce reproductions into three separate methods, the Russian technique, the American technique and the British technique. They were named for where their defining practitioners worked, mainly Gerasimov, Krogman and Neave, respectively (Stephan 2006). The methods are defined in how they use different methods of reproducing the facial soft tissues on the reconstruction, yet this is inherently false (Stephan 2011).



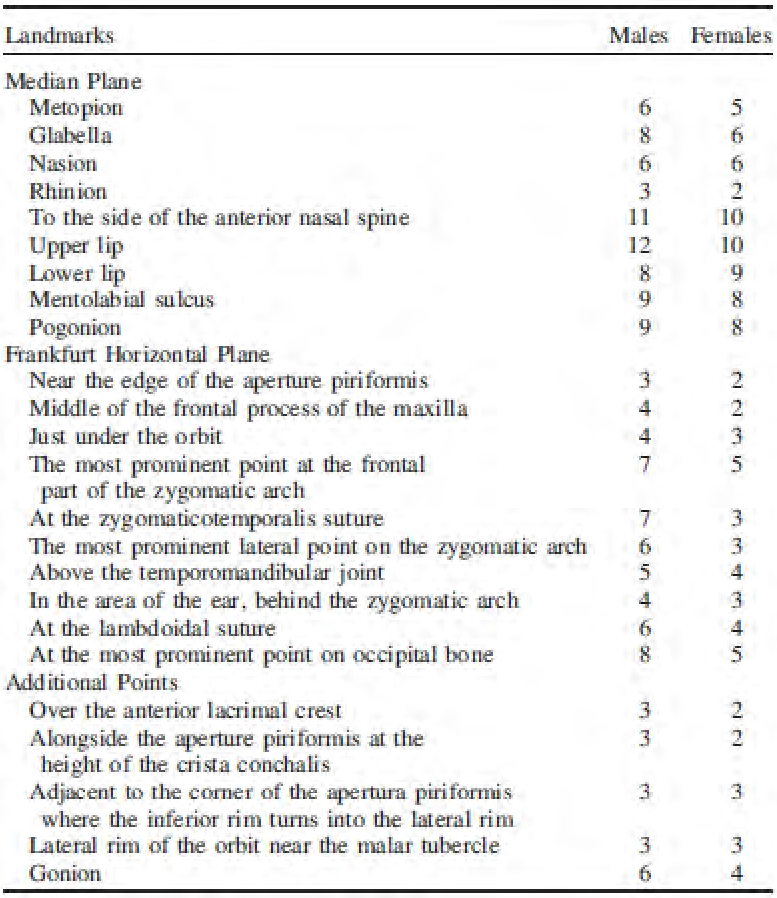
Generic Soft Tissue Thickness Values

Landmark	Weighted Mean	Range
Midline landmarks		
Opisthocranion	6.5	–0.5–13.5
Vertex	5.0	1.5– 8.5
Glabella	5.5	2.5– 8.5
Nasion	6.0	1.0–11.0
Mid-nasal	4.0	0.5– 8.0
Rhinion	3.0	0.0– 5.5
Subnasale	12.5	3.0–22.5
Mid-philtrum	11.0	3.0–18.5
Labrale superius	11.5	3.0–20.0
Labrale inferius	13.0	5.0–21.0
Mentolabial sulcus	11.0	5.5–16.5
Pogonion	11.0	3.5–18.5
Gnathion	8.5	–1.0–18.0
Menton	7.0	0.0–14.0
Paired landmarks		
Mid-supra-orbital	6.0	1.5–10.0
Mid-infra-orbital	7.0	–4.0–18.0
Alare curvature point	9.3	2.5–16.0
Gonion	10.0	–8.0–27.5
Zygion	6.0	3.0– 9.0
Supra canine	9.5	3.5–15.5
Infra canine	10.5	4.5–16.5
Supra M^2	26.0	10.0–42.0
Infra M^2	19.5	6.0–33.0
Mid-ramus	17.5	6.0–28.5
Mid-mandibular border	10.5	–2.5–24.0

Note: As compiled and published by Stephan and Simpson (2008a). Values in mm. Range is from mean minus 3 z-scores to mean plus 3 z-scores. (Published with permission)

Table 2.1 The generic soft tissue thickness value table produced by Stephan and Simpson (2008 reported in şcan & Steyn 2013, pp 370)

The Russian technique, primarily based on erasimov’s work, is known to only require the reconstruction of the facial muscles to the exclusion of soft tissue depth measurements. This is incorrect. Gerasimov measured the soft tissue thickness of 71 freshly deceased individuals and produced his own set of soft tissue thickness values (see table 2.2) which he used extensively in his own work, though they were omitted in his 19 1 wor k ‘The Face Finder’ (Stephan 2011; Ullrich & Stephan 2011). Looking at his work and images taken during the reconstruction process it is clear that he used soft tissue landmark markers (Stephan 2006). Only the 2 most superficial muscles of mastication, the temporalis and masseter muscles, would be constructed as he did not rely on determining the muscles from the skull alone. Then, using his own values, Gerasimov would construct the rest of the face (Ullrich & Stephan 2011).



Landmarks	Males	Females
Median Plane		
Metopion	6	5
Glabella	8	6
Nasion	6	6
Rhinion	3	2
To the side of the anterior nasal spine	11	10
Upper lip	12	10
Lower lip	8	9
Mentolabial sulcus	9	8
Pogonion	9	8
Frankfurt Horizontal Plane		
Near the edge of the aperture piriformis	3	2
Middle of the frontal process of the maxilla	4	2
Just under the orbit	4	3
The most prominent point at the frontal part of the zygomatic arch	7	5
At the zygomaticotemporalis suture	7	3
The most prominent lateral point on the zygomatic arch	6	3
Above the temporomandibular joint	5	4
In the area of the ear, behind the zygomatic arch	4	3
At the lambdoidal suture	6	4
At the most prominent point on occipital bone	8	5
Additional Points		
Over the anterior lacrimal crest	3	2
Alongside the aperture piriformis at the height of the crista conchalis	3	2
Adjacent to the corner of the apertura piriformis where the inferior rim turns into the lateral rim	3	3
Lateral rim of the orbit near the malar tubercle	3	3
Gonion	6	4

Table 2.2 The mean tissue depths (mm) produced by Gerasimov (reported in Ullrich & Stephan 2011, pp 471).

In comparison, the American technique is known to only require the use of soft tissue depths to the exclusion of the facial musculature (Ullrich & Stephan 2011). Yet, this method does in fact use of facial musculature to ensure that even with the use of soft tissue depths, the reconstruction creates realistic contours and facial expressions (Stephan 2006).

Instead, the soft tissue landmarks used are frequently sparsely spaced. A good knowledge of the facial anatomy and how to interpret the bony landmarks of the skull is necessary to then fill in the spaces between those landmarks and recreate realistic facial contours. This knowledge will also aid in understanding the muscles of the face not attached directly to the skull (Stephan 2006).

Overall, the combination or Manchester technique is a continuum along which all the other methods fall, as both the Russian and American techniques combine soft tissue depths and the facial musculature (Stephan 2006).

The lack of standardization is slowly being improved on, and it must be acknowledged that each method of measuring the soft tissue thicknesses, imaging the soft tissues, approximating the face and even which data set is used has its pros and cons and contributes to the overall variation seen in the data and reconstructions (Cavanagh & Steyn 2011).

2.2.4.4. DIFFICULTY IN APPLYING GUIDELINES

There is variation in the appearance and presence of the facial muscle guidelines, which have their own issues. Although the application of facial reconstruction guidelines is subjective, empirically untested, soft tissue prediction guidelines still form the fundamental basis of the facial reconstruction process as they did in the past (Stephan 2003).

The average soft tissue depths as developed in the late 1800s have essentially been used unchanged up until recently (although data collection methods have been refined). Recent developments by Simpson and Henneberg (2002) linking soft tissue depths with face size certainly seem to be a promising future exception here but since they have not been reported to be employed in the facial approximation process they remain irrelevant to this discussion.

e rasimov's own prediction guidelines of the facial features can be difficult to follow and his results difficult to reproduce as he did not publish or fully describe all his methods (Ullrich & Stephan 2011).

There are limits to current methods of facial reconstruction which limit the ability to generate accurate facial anatomies and hence regional faces. Current facial reconstruction guidelines rely largely on the practitioners' subjectivity and assumptions of their accuracy (Stephan & Henneberg, 2001; Stephan 2003). These guidelines do not cover every facial trait, forcing the practitioner to rely even more on their experience and intuition (Stephan 2003).

Such as for the construction the lips, for which there are guidelines on determining the mouth width and lip heights, even though people with similar occlusal patterns have different lip shapes (Stephan 2003). In the literature the same guidelines are reported to be used again and again, but how can so few guidelines be expected to produce a recognizable face from just the skull (Stephan 2003)? Even though a comprehensive knowledge of facial anatomy and much experience may lower the error and subjectivity that occur in facial reconstruction, scientifically tested and formulated guidelines are needed to assure the lowest rate of error and least amount of subjectivity (Stephan & Henneberg 2001).

However, Wilkinson (2010) argues that with a detailed knowledge of anatomy and the facial morphology, and adhering strictly to the guidelines, artistic interpretation is minimised. Where guidelines conflict with what is seen on the skull, they can then be adjusted for. She concludes that the majority of facial morphology in facial reconstruction can be scientifically predicted, with allowance for age changes and other factors which cannot be predicted. She emphasises that recognition is the primary objective, not an exact likeness.

2.2.4.5.DIFFERENCES BETWEEN THE DIFFERENT BIOLOGICAL FACTORS

Soft tissue thickness data sets are used to render a face of specific ancestry group, sex, age and body mass. Most data sets and studies emphasize subdivision of the data by these factors as surely they will have individualising affects on the soft tissues and, therefore, the face. However, are the differences reported between the various groups significant enough as to be of use or are they negligible? Is subdivision by biological factors justified (Stephan & Simpson 2008)?

Wilkinson (2004 reported in şcan & Steyn 2013) found that males had thicker tissues in most areas of the face, particularly the brows, mouth and jaw, in contrast females had thicker tissues in the cheeks. When uy omarc'h *et al.* (2013) compared the results of soft tissue measurements of 500 French individuals to six other data sets, they found that overall the differences caused by most biological factors were negligible, but found that sex and fatness or face build (through estimated BMI) had a greater impact on soft tissues than did ancestry or age. Sex had the greater influence around the lateral superior orbital region, the nasal bridge and the anterior superior alveolar process. Males had overall greater differences, between the different data sets, than females, though the differences between the sexes were low. The factor of greatest influence, they found, was fatness. Males of higher fatness had higher soft tissue measurements.

This suggests that there are differences between the sexes which make separating data sets by sex necessary.

Stephan and Simpson (2008) compared ‘caucasoid’ and ‘non-caucasoid’ measurements and found that the affects of ancestry on soft tissue depths was relatively weak, with the data showing broad but similar measurements with any differences likely resulting from the different measuring techniques used (şcan & Steyn 2013).

The uy omarc’h *et al.* (2013) study found there were no statistically significant patterns of variation influenced by age and determined that applying age specific data would result in negligible differences to a reconstruction. Similar results were seen between different population or ancestry groups. The differences, they argued, seen in the face would not come from the soft tissues but the features of the underlying bony skull being translated onto the face itself.

Cavanagh and Steyn (2011) used computer tomography scanning to determine soft tissue thickness values for South African black females. They determined that there were significant differences in the values for the study population compared to other databases and that this must be due to geographically different populations having different soft tissue thicknesses. This is interesting when considering that uy omarc’h *et al.* (2013) found that the populations with the most similar results to their own were the South Africans of the Cavanagh and Steyn (2011) study of a South African Black female sample. The two populations, French and South African, are geographically distant but the soft tissue thickness measurements indicate that population specificity is in fact lower than expected. We must also be aware that similarity between two populations does not measure population variability in soft tissue thickness.

Soft tissue thickness databases give limits on the tissue depths at the set facial landmarks when estimating the shape and contours of the face and, due to this, they suggested that for certain populations, different sets of landmarks should be used for certain ancestry specific characteristics. Such as in South African Blacks who, in general, have more prominent and prognathic lips even as the data shows that lip thickness occurs more on the alveoli and not the teeth (Cavanagh & Steyn, 2011).

A study of 1695 individuals from different population groups (including, Koreans, Buryats, Kazakhs, Bashkirs, Uzbeks, Armenians, Abkhazians, Russians and Lithuanians) looked at the soft tissue measurements within and between the groups (Lebedinskaya & Veselovskaya 1993). They could produce average matrices using soft tissue depths, with a high degree of similarity. There was a high degree of correlation of the facial features between the five morphological zones of the face (forehead, nose, cheekbones, mouth and lower jaw). This correlation was also seen in the soft tissue distribution between the forehead, cheekbones, nasion and mandibular regions. There was a lack of correlation between the oral and nasal areas with the other facial regions that indicated that there was some variability of the soft tissue thicknesses in those regions. Further analysis showed that the similarity between the features produced three clusters of the facial regions. Each of those clusters demonstrated that there was a high degree of correlation, or similarity, among the features of those clusters.

The tissue thicknesses varied between the sexes and between the groups, illustrating differences between the groups for different points. They noted that there was a tendency for increased soft tissue of the nasal region for those of more European ancestry than those of more Mongolian, or Eastern, ancestry (Lebedinskaya & Veselovskaya 1993). Overall, the study showed that even those ancestry groups found to be the most different from each other displayed an overlap, making the separation of data sets difficult, and even with this overlap, shifts in the mean did affect accuracy.

The variation and significant differences in the landmark depths of different data sets (De Greef *et al.* 2006; Cavanagh & Steyn, 2011) indicate that there are more factors that need to be considered when establishing them. As it has yet to be systematically tested, şcan & Steyn (2013) suggest it is best to continue using sex and ancestry specific data when attempting facial reconstruction.

2.2.4.6.FACIAL FATNESS AND ITS IMPACT ON SOFT TISSUE THICKNESS

We must also consider that muscles are not the only soft tissues that construct the face. Soft tissues, like facial fat, have a weaker relationship to the skull than the muscles. The relationship of bony and soft tissue morphology as represented in facial reconstruction is reliant on the expertise of the practitioner (Decker *et al.* 2013) and standardised data sets for tissue thicknesses which are normally grouped as emaciated, normal and obese (Gatliff 1984; De Greef *et al.* 2006).

Most reconstructions assume that the target individual falls into the ‘normal’ range of body fatness and, as facial fatness cannot be estimated from the skull (Wilkinson 2010), we cannot rely on such an assumption. Soft tissue thickness data sets concentrate on averages for ancestry groups and not the full range of inter-individual variation. The use of radiographs from radiographic databases to determine soft tissue thicknesses from living individuals often means that the relevant information on body weight was not available (Cavanagh 2010; Cavanagh & Steyn 2011). In other cases, individuals who were considered to not be of a ‘normal’ body weight were actively excluded from the study (Aulsebrook *et al.*1996; Kurkcuoglu *et al.* 2011). We must then conclude that underweight and overweight individuals were included in the analysis and their influence on the range of variation is not known.

The De Greef *et al.* (2006) study used ultrasound to look at soft tissue thicknesses of 967 whites and their relationship to BMI. They found that BMI had a greater impact on the soft tissue measurements of males than females, but that, irrespective of sex, some of the measurements had no correlation with age or BMI. Certain areas of the face, the mandible and maxilla, were more variable with changes in BMI, which showed that different body builds and weight do have an effect on the soft tissue thicknesses of the face. The wide range of variation of the measurements further demonstrated the range of variation between individuals.

Cavanagh and Steyn (2011) found the landmarks with higher values occurred on the mandible and maxilla (the mouth and cheeks) and were areas which were most variable with changes in body weight. This reflects on how body build and weight can influence the soft tissues, and the wide ranges of some measurements which reflects on inter-individual variation.

The Dong *et al.* (2012) study of a Northern Chinese Population found that males had overall greater tissue thicknesses than females over any BMI category, but the range increased with higher BMI, and only a third were significantly different. Females had greater tissue thicknesses at different facial regions than males as BMI changed. They found that the majority of the differences occurred in individuals of 'slender' or 'normal' BMI, while only two landmarks showed significant differences between males and females in those of obese BMI levels.

When the different databases for soft tissue thicknesses are compared, there are significant differences found between the landmark measurements (De Greef *et al.* 2006; Cavanagh & Steyn 2011). The Guyomarc'h *et al.* (2013) study compared seven data sets of and found that the factor which had the greatest influence on soft tissue thicknesses and exhibited the greatest variation between the different data sets was fatness (their estimated BMI or face build).

There is often no information as to the target individuals weight status in a forensic reconstruction case (Guyomarc'h *et al.* 2013) and there is thus a lack of information on the influence of body fat percentage and body mass index of the soft tissue depths of the face (Decker *et al.* 2013).

2.3. FAT TISSUE

Fat, or adipose tissue, is a specialized type of loose fibrous connective tissue that contains a large number of adipose cells, non-fat cells, connective tissue matrix, and vascular and neural tissues (Ibrahim 2009). It forms from the mesenchyme, largely prenatally and in the first year of life (Van De Graaff 2000). These adipose cells store fat in their cytoplasm, which causes them to swell as the amount increases. Adipose tissue is found throughout the body and concentrates around the kidneys, the hearts surface, around the joints, in the hypodermis of the skin, and in the breasts of sexually mature females (Van De Graaff 2000).

Fat is the most mutable of the solid properties of the body and has the ability to undergo a considerable number of changes in volume during an individual's life (Sloan 1970; Fraser *et al.* 2006). There are different types of adipose tissue. The most common is white adipose tissue, which is the fat found throughout the body that acts as an energy reserve. Infants are born with brown adipose tissue. This specialized adipose tissue allows for the direct conversion of mitochondrial energy into heat instead of ATP, assisting in the newborns thermoregulation. Brown adipose tissue volume decreases with age. Other types of adipose tissue include bone marrow fat and mammary fat (Gimble & Nuttall 2004).

Peripheral adipose tissue is metabolically active, using and storing triglycerides and fatty acids as the body requires them. It forms fat pads in the palms of the hands, soles of feet, and in the infrapatellar and retro-orbital regions where it acts as a biomechanical cushion, protecting the underlying bones and tissue structures from trauma and injury (Gimble & Nuttall 2004).

It acts as an energy reservoir, and protects and supports the organs (Van De Graaff 2000). It is also a poor conductor of heat and so acts as an insulator of the body (Van De Graaff 2000) and as a mechanical cushion and energy reservoir, storing energy and lipids (Gimble & Nuttall 2004).

There are two extremes of body fat distribution which are android and gynoid (Mueller *et al.* 1986). Android obesity occurs when fat concentrates in the upper and central subcutaneous region, while gynoid obesity occurs when fat is distributed more generally. The centralized obesity is more common in males, while the generalized gynoid obesity is more common in females, who tend to have a greater proportion of subcutaneous fat, which is carried near the body's surface (Hattori *et al.* 1991).

Those who fall under the 'obese' category tend to have relatively less overall subcutaneous fat and have an android obesity distribution of fat, which may be due to larger intra-abdominal fat deposits (Mueller at al. 1986). This is displayed by larger abdominal and gluteal regions.

2.3.1. BODY WEIGHT, FATNESS AND OBESITY

Body weight depends on a number of factors, not only adipose tissue. Obesity is the deposition of excessive amounts of body fat. A precise definition is impossible, though generally an increase of 20% above the norm for others of the same sex, age, height and race is considered obese (Sloan 1970), a BMI of over 25kg/m^2 (Centers for Disease Control and Prevention 2014), or having a body fatness greater than 32% in females and 25% in males (Muth 2009).

However, describing an individual as obese must be approached with caution. Extra weight may not be due to fat but greater bone or muscle mass, as both are heavier than fat (Sloan 1970). There are a number of ways to measure the body's fat stores. Methods for measuring fatness include underwater weighing, measuring selected skinfolds, ultrasound and X-rays (Sloan 1970).

2.3.2. METHODS OF ESTIMATING FATNESS

To calculate body fat percentage, it is necessary to first calculate body density. There are low correlations between height, weight and density which indicate that estimation of fatness from height and weight are not adequate

Density can be calculated with the known mass and volume of the body, with the assumption that the body comprises of both fat and lean mass, both of which are of a constant, known density (Sloan 1970). If the body density is known the ratio of these parts can be calculated. At normal body temperature, the density of human fat is 0.9 g/ml and lean body mass is 1.1 g/ml7 (Siri 1961). With these known constants, variations in the proportion of bone and muscle do not significantly affect the lean body mass.

Directly weighing participants for density measurements is difficult. Underwater weighing is one of the most reliable methods of estimating body fat for a living individual, but the equipment for direct determination of body fat is not portable and underwater weighing cannot always be used, simpler means of predicting density and body fat are necessary (Sloan *et al.* 1961; Sloan 1970). Calculations have been developed to use other means of determining body density and, so, body fat percentage.

The vertical skinfold thickness above the iliac has the highest correlation with body density in females (Sloan *et al.* 1961; Sloan *et al.* 1962). The correlation can be improved with the addition of the skinfold from the back of the arm (Sloan *et al.* 1962). The addition of skinfold measurements of the abdomen and scapular are also recommended (Sloan & Shapiro 1972). The skinfold thickness over the front of the thigh was found to be the best predictor of density in males. This was improved with the addition of the skinfold from the inferior angle of the scapula (Sloan 1967).

Measurements from skinfolds are popular for determining subcutaneous fat, as they are simple to perform and generally reproducible (Sloan 1967).

Skinfolds are located visually and taken with the subject standing straight with their arms at their sides (Sloan & Shapiro 1972). The actual measuring is performed by lifting a fold of skin and adipose tissue from the underlying muscle with the forefinger and thumb. The thickness is then measured by special callipers which exert a constant pressure- Sloan and Shapiro (1972) determined that differences different callipers exerted pressures within the range 10-90g/mm^2 and have only a small effect on the skinfold measurements. They found that the different calliper measurements were comparable and the prediction of body fat using different callipers is similar. The varying thicknesses of the measurements is then due to the subcutaneous adipose tissue or fat, as skin thickness is fairly uniform, approximately 1.2 mm (Sloan 1970).

Density can then be calculated using the skinfold measurements and a regression equation (Sloan 1970). The calculated mean body fat is expressed as a percentage of body weight (Sloan & Shapiro 1972).

2.3.3. BMI AS A MEASURE OF FATNESS

With the increasing levels of obesity worldwide, various indices have been used for the clinical measuring of fatness (Smalley *et al.* 1990). Body Mass Index or BMI is a method used to measure body fatness or adiposity by adjusting body weight for the individual's height. It is a commonly used method for determining if a individual is underweight, of average or normal weight, overweight or obese because the technique is simple, cheap, non-invasive and quick (Gallagher *et al.* 1996), as well as the most commonly used method to ascertain obesity in epidemiological studies (Luke *et al.* 1997).

However, there are limitations in its usefulness as a measure of fatness.

An individual's BMI can be affected by factors such as height, relative sitting height and body proportions, and the use of weight causes the BMI to reflect both the lean and fatty tissue measurements (Garn *et al.* 1987). For instance, a individual with shorter legs for their height could have a higher BMI than what their actual body fat percentage would indicate. With traditional use of BMI to estimate fatness, an individual with a high degree of muscular development but little fat could still be classified as obese (Deurenberg *et al.* 1999). The use of weight compared to others of similar sex, age and height to determine fatness is also unsatisfactory. Higher bone and muscle mass can cause an individual with less body fat to be considered to obese when they are not (Sloan 1967). When age is factored in, BMI can become a better measure of lean tissue mass than fatness (Garn *et al.* 1986). In this way BMI and body weight are unreliable measures of obesity, instead body fat percentage should be estimated (Sloan 1970).

2.3.4. SEX AND ANCESTRY-RELATED DIFFICULTIES IN DETERMINING FATNESS.

Studies indicate that using BMI as a measure of body fat percentage requires greater knowledge of the factors which could influence the measurements, which include biological, environmental and socio-economic factors which differ from ancestry group and location. BMI, while correlated with body fat percentage (Smalley *et al.* 1990), should not be used alone as an indicator of the level of fatness of an individual. Instead, its usefulness is in its easy and non-invasive methodology, and its' clear cut-off points to determine if an individual is underweight, of average weight, overweight or obese. Other factors can affect fat distribution and presence such as sex and ancestry.

While the variation of body fat is wide in both sexes, females have approximately double the body fat of males (Sloan 1970), with most females having higher BMI measurements than males of similar populations.

Smalley *et al.* (1990) determined that BMI and body fat percentage were correlated. The BMI of females was more strongly correlated to body fat percentage than the males but, overall, the sex-specific BMI measurements were not correlated significantly more so than the generalized BMI. Still, they indicated that measurements of height and weight would not accurately assess body fat percentage of an individual. Stature, lean body mass and body proportions were mentioned as potential reasons for the relationship between BMI and body fat percentage, and they included unknown factors as yet unidentified which might affect the accuracy of body mass indices.

The 1994 study by Wang *et al.* showed that height and weight based equations for body fat are ancestry group specific and can under or over estimate fatness for different ancestry groups than those they were developed for. They determined that those of Asian ancestry had higher body fat than Whites at similar BMI, indicating that BMI is not a reliable indicator of body fat. This is likely due to the weight used in the BMI equation is the sum of not only fat but the muscle, bone and other tissues that make up the body.

The 1996 study by Gallagher *et al.* suggested that that while the relationship between BMI and fatness was influenced by age and sex, ancestry was not a factor. They analysed measurements from 202 Black African and 504 White participants to test the assumption that BMI represented adiposity independent of other factors such as age, sex and ancestry. They found that when comparing older and younger participants of similar BMI, that the older participants had higher body fat percentages. Females were found to have significantly higher body fat percentages compared to males of similar BMI and this was consistent for all age groups.

Yet, when comparing Black African and White participants, they found that BMI was similar between the two groups, independent of age or sex. They did find significant differences in the waist to hip ratios between Black African and White participants though they possessed similar levels of fatness. They also analysed limb length and its relationship to BMI and fatness by measuring tibia length to examine if increased limb length would increase body weight and BMI for individuals of similar height. There was no significant difference found and they suggested that the increase in fat percentage as age increases was not associated with senescence-related stature loss (Gallagher *et al.* 1996).

The Luke *et al.* (1997) study compared the BMI and body fat percentage of three populations with a common West African genetic ancestry. They determined that within each population BMI was a good predictor of fat percentage but varied between the populations at similar BMI.

As with other studies (Garn *et al.* 1987; Deurenberg *et al.* 1999), females were found to have greater body fat percentage compared to males of similar BMI and that BMI increased as industrialization or Westernization increased. The differences in body composition between the sexes of most studies were largely attributed to the differences in hormones and genetics, however, they determined that the populations' common ancestry should not cause the differences seen between the same sexes of those populations. Instead, they determined that the most important factor in the differences between the sexes of the populations was environment. This included the differences in physical activity and food availability which could account for the different sites of fatness found between the ancestry groups.

Deurenberg *et al.* (1998) performed a meta-analysis of a number of studies across a number of ancestry groups; including Thai, Polynesian, Indonesian, Ethiopian, Chinese, African American, as well as European and American Whites. This was done in an effort to evaluate if and where there should be BMI cut-off levels for measuring obesity in the different ancestry groups. They agreed with the previous studies that the relationship between BMI and body fat is dependent on sex and age, but found that there were different levels of body fat percentage for the different ancestry groups at similar BMI. They noted that African Americans had an overestimation of fat for the same BMI as Whites, and that levels of body fat percentage as an indicator of obesity were reached at a lower BMI for many groups.

They (Deurenberg *et al.* 1999) suggested that different dietary and exercise patterns, as well as body builds may be influencing factors in these differences. For example, a individual of a more compact or stocky build may have more muscle mass and so a slimmer individual of the same BMI may have a higher level of body fat. They also found that there were differences within the ancestry groups. Comparing the differences in the relationship between BMI and fat percentage in the two White groups showed that European Whites had a higher fat percentage than American Whites. A similar difference was found between the Northern and Southern Chinese groups.

Deurenberg *et al.* (1999) suggested that further studies should include body build parameters, such as sitting height and skeletal widths, and suggested that further intra-ancestry group studies should be performed as the differences within these groups could be of some importance.

The 1999 Deurenberg *et al.* study determined that increased physical activity influenced BMI and body fat percentage as it leads to an increase in muscle mass. This meant that individuals with smaller body builds can have higher body fat percentages than those with larger body builds at similar BMI. This indicated that body build, not just weight or height, influences fatness.

2.3.5. THE AGING FACE AND ITS SOFT TISSUES

The face consists of a complicated structure of bone, muscle, vessels and fat. The facial fat is partitioned into separate anatomical compartments of subcutaneous and deep fat (Rohrich & Pessa 2007). These fat compartments help in constructing the contours of the face (Donofrio 2000) and can be found superior and inferior to the muscles, which facilitate the gliding motion of the muscles in action. These compartments are composed of a number of discrete anatomical regions which do not age as a confluent mass, but instead age independently of each other (Rohrich & Pessa 2007).

Aging of the soft tissues starts in the 20s (Albert, Ricanek & Patterson 2007). In the face of a younger individual there is an even and full distribution of fat, both deep and superficial, which smoothes it's appearance (Donofrio 2000), and allows for a smooth transition between the different fat compartments. As an individual ages contours form as changes in the volume and positioning of those compartment alter their shape (Rohrich & Pessa 2007).

The older face becomes more compartmentalized as the separated compartments become demarcated; with the temples, lateral cheek and suborbital region becoming more prominently convex, the mandible and cheeks losing their arched shape, the lips becoming more angular, the jawline scalloped and the brow no longer projecting outward (Donofrio 2000). Visual changes become more prominent in the 40s and more prominently in the 50s, with further drooping of the feature (Albert, Ricanek & Patterson 2007).

While the facial muscles lose their tone, aging causes hypertrophy and atrophy of the different facial regions and fat compartments too (Donofrio 2000). Hypertrophy is the enlargement of the lipid tissue stored in individual adipocytes, while atrophy is the loss of it (Fraser *et al.* 2006).

The jowl, lateral nasolabial fold, lateral labiomental crease and lateral malar areas undergo hypertrophy, while the periobital, forehead, buccal, temporal and perioral regions undergo atrophy (Donofrio 2000). This can be seen in the upper face losing volume and becoming more hollow in appearance, while the lower face can appear to gain volume.

osmetic facial surgery and implants largely attempt to 'correct' the signs of aging by shifting or adding the more hypertrophic tissue into the areas of atrophy, filling in the areas of volume loss. As the volume of a fat compartment decreases it pulls on other compartments, this loss of support between the compartments also puts strain on them, lessening their projection and leading to the changes and distortion in facial shape associated with aging (Rohrich & Pessa 2007).

This loss of volume in the face causes the skin to droop in an older individual; as opposed to a younger individual whose skin would contract more smoothly; causing the sagging and wrinkled appearance associated with aging (Donofrio 2000).

3. MATERIALS AND METHODS

The study was performed in two separate stages. The first stage was to determine whether measurements taken from the LODOX® Statscan images were acceptable substitutes for physical soft tissue measurements.

The second stage is the principle study linked to the aim outline in the introduction to determine if soft tissue thickness was due to facial fatness, sex or population origins.

This two stage approach was necessitated by the non-linear distortion that occurs with radiographs. The distortion occurs as "a result of the imaging process: X-rays from a point source spread out before being captured by a detection device such as a photographic plate or an electronic CCD sensor" (Beets 2007, pp 4).

A study by Stull *et al.* (2013) demonstrated that measurements taken from the LODOX® Statscan images were acceptable substitutes to physical measurements taken on dry bone, especially with length measurements of those taken on the Y-axis, while there were negligible differences when measurements were taken at an angle on the Y-axis. The interest then was to determine if the same could be said for soft tissues measured on LODOX® images.

3.1. MATERIALS

In the initial section of this study to determine if measurements from LODOX® Statscan images were appropriate analogues for physical measurements, 15 heads from cadavers were used. The cadavers were from the University of Cape Town's Health Sciences Faculty.

The sample consisted of seven female and eight male cadavers, of which five were coloured and ten were white. The ages recorded for the cadavers were between 36 and 101 years. The cadaver heads were removed between C1 and C2, and are used for the faculty's spinal workshops.

In the living volunteer section of the study, the sample size was 67. It consisted of 17 (25.37%) males and 50 (72.46%) females, between the ages of 18 and 50 years. White females were the largest group, with 24 of the total sample population, while Black African females were the second largest group at 13. The smallest groups were Indian/Asians and Other. Of the sample, only two volunteers did not self-identify their population group. The population and sex distribution is summarized in Table 3.1.

Table 3.1 The sex and ancestry distribution of the living participant sample

Population	**Sex**		**Total**
	Male	**Female**	
Black African	9 (13.43%)	13 (19.40%)	22 (32.84%)
Coloured	3 (4.48%)	8 (11.94%)	11 (16.42%)
Indian/Asian	0 (0.00%)	2 (2.99%)	2 (2.99%)
White	5 (7.46%)	24 (35.82%)	29 (43.28%)
Other	0 (0.00%)	1 (1.49%)	1 (1.49%)
Unidentified	0 (0.00%)	2 (2.99%)	2 (2.99%)
Total	17 (25.37%)	50 (74.63%)	67 (100%)

The sample population were all volunteers who were recruited from the student population of the Health Sciences Faculty of the University of Cape Town, and were invited to participate in this study through posters, flyers, and lectures to mention the study and how to contact the researcher. Only participants over the age of 18 and under 50 years, and females who were not pregnant at the time, were accepted.

Due to how the University of Cape Town accepts students following the demographics of South Africa, the University student population is a true reflection of the South African population.

3.2. METHODS

The study used LODOX® Statscan images of living individuals to determine the relationship between tissue thickness and body fatness. Measurements of set facial landmarks were taken from the LODOX® Statscan images and analysed.

3.2.1. FACIAL LANDMARKS AND ASOCIATED MEASUREMENTS

For this study 15 landmarks were defined and the soft tissue thickness measured at each landmark on LODOX® Statscan® images. The landmarks were determined according to the most commonly used landmarks analysed in the literature (Stephan & Simpson 2008; Farkas 1994) and by determining which landmarks will be best identified in LODOX® scans.

In the anterior-lateral view, both the left and right side for each of the three measured landmarks (Euryon, Zygion and Gonion) was measured and then averaged, as the 2011 study by Munoz *et al.* determined that “no significant differences were found when comparing the soft-tissue thickness on the right and left sides” of the face. The same result was determined by u yomarc’h *et al.* (2013).

The bony facial landmarks and their definitions are listed in Table 3.1 and their locations on the skull shown in Figures 3.1 and 3.2.

Table 3. 2 Summarized definitions of the facial landmarks as seen on the LODOX® images

Measurements		Definitions	
E_R & E_L	Euryon (Right) & Euryon (Left)	Bony	The anatomical points of the greatest curvature on the right and left parietal bones that lie at the greatest transverse diameter from each other (Miller *et al.* 2004).
		Soft Tissue	The points on the soft tissue directly overlying the bony points of Euryon that lie at the greatest transverse diameter from each other (Miller *et al.* 2004).
Z_R & Z_L	Zygion (Right) & Zygion (Left)	Bony	The points at the maximum, most lateral outer curvature of the right and left zygomatic arch (Aulsebrook *et al.* 1996; Işcan & Steyn 2013).
		Soft Tissue	The soft tissue point perpendicularly overlying the bony zygomatic arch (Aulsebrook *et al.* 1996; Stephan & Simpson 2008; Cavanagh 2010; Işcan & Steyn 2013).
Go_R & Go_L	Gonion (Right) & Gonion (Left)	Bony	The point of the right and left mandibular angle located on the most lateral aspect of the border of mandibular angle, where the gonial flare causes a lateral projection of the mandible (Stephan & Simpson 2008; Işcan & Steyn 2013).
		Soft Tissue	The soft tissue point directly overlying the hard tissue Gonion, the most lateral point on the mandibular angle (Stephan & Simpson 2008; Işcan & Steyn 2013).
V	Vertex	Bony	The point located at the highest midline ectocranial point of the maximum curvature of the skull vault (Stephan & Simpson 2008).
		Soft Tissue	The soft tissue point directly perpendicular to the hard tissue of the bony landmark for the Vertex, the point at the maximum soft tissue curvature of the head when in the Frankfurt Horizontal plane (Stephan & Simpson 2008; Işcan & Steyn 2013).
Mot	Max. occipital point	Bony	The anatomical point on the occipital bone located at the greatest distance from the Glabella (G), measured transversely,(Stephan & Simpson 2008).
		Soft Tissue	The soft tissue directly perpendicular to the bony point for the maximum transverse distance from the Glabella, also known as the Opisthocranion (Stephan & Simpson 2008; Işcan & Steyn 2013).
R	Rhinion	Bony	The anatomical point located at the inferior point of the internasal suture, the edge of the nasal bone at the superior nasal osseocartilaginous junction (Aulsebrook *et al.* 1996; Stephan & Simpson 2008).
		Soft Tissue	The soft tissue directly perpendicular to the bony point of Rhinion (Aulsebrook *et al.* 1996; Stephan & Simpson 2008).
Nt	Nasal tip	Bony	The anatomical point located at the tip of the bony projection of the acanthion (Aulsebrook *et al.* 1996).

		Soft Tissue	The point located on the most prominent anterior curve of the projection of the soft tissue of the nose, known as Pronasale (Aulsebrook *et al.* 1996; Işcan & Steyn 2013).
Mp	Mid-philtrum	Bony	The anatomical point occurring in the midpoint of the curvature found in the midline point midway between the base of the nasal spine and Prosthion (Pr) on the anterior edge of the maxillae (Stephan & Simpson 2008) before the anterior nasal spine starts (Işcan & Steyn 2013). The orthodontic point called Point-A or Subspinale (Aulsebrook *et al.* 1996).
		Soft Tissue	The midline point most perpendicular to the bony point, between the base of the nose, or columella, and the upper lip margin (Aulsebrook *et al.* 1996).
Pr	Prosthion	Bony	The point on the maximum labial curvature of the crown of the most anterior upper central incisor (Aulsebrook *et al.* 1996).
		Soft Tissue	The anatomical point located at the maximum anterior curvature of the upper lip margin, often termed the *Labrale Superius* (Aulsebrook *et al.* 1996). The midline soft tissue point at the vermilion border of upper lip (Stephan & Simpson 2008; Işcan & Steyn 2013).
Ml	Midlip	Bony	The anatomical point located on the maximum lower curvature of the edge of the most projecting anterior upper central incisor (Aulsebrook *et al.* 1996).
		Soft Tissue	The soft tissue point where the upper and lower lip meet in the facial midline, most perpendicular to the bony point (Aulsebrook *et al.* 1996). Also called Stomion (Işcan & Steyn 2013).
In	Inion	Bony	The anatomical point located at the anterior edge of the inferior alveolar ridge of the maxillae (Stephan & Simpson 2008) where the lower sentral incisors are level with the cementum-enamel junction (Işcan & Steyn 2013).
		Soft Tissue	The anatomical point located on the midline soft tissue point at the vermillion border of lower lip (Stephan & Simpson 2008), often termed the *Labrale Inferius* (Aulsebrook *et al.* 1996; Işcan & Steyn 2013).
Sm	Supra-mentale	Bony	The anatomical point occurring in the midpoint of the deepest curvature on the mandible, between the Infradentale (In) and the Pogonion(Po), midway between the superior edge of the mandible and Gnathion, on the anterior edge of the mandible (Stephan & Simpson 2008; Işcan & Steyn 2013), also known as Mid-Labio Mentale or orthodontically as Point B (Aulsebrook *et al.* 1996).
		Soft Tissue	The soft issue point located at the deepest point of the labiomentale crease, the most midway point between the lips and the chin (Aulsebrook *et al.* 1996).

Po	Pogonion	Bony	The point located at the most anterior midline point on the maximum curvature of the mental eminence of the mandible, also known as Anterior Symphyseal (Aulsebrook *et al.* 1996; Işcan & Steyn 2013).
		Soft Tissue	The soft tissue point perpendicular to the bony point at the maximum anterior soft tissue curvature of the chin (Stephan & Simpson 2008; Işcan & Steyn 2013).
Gn	Gnathion	Bony	The point at the most inferior midline point of the curvature of the menton of the chin (Aulsebrook *et al.* 1996; Işcan & Steyn 2013).
		Soft Tissue	The soft tissue point perpendicular to the bony point at the lowest median soft tissue curvature of the soft tissue menton of the chin (Aulsebrook *et al.* 1996; Işcan & Steyn 2013).
Op	Ophryon	Bony	The anatomical point found on the frontal bone at the deepest curvature of the dip between the maximum curvatures of Glabella (G) and frontal eminence, which is also known as Supra-Glabella. In the event that there is no dip then the point is determined to be the midpoint of the two curvatures (Aulsebrook *et al.* 1996).
		Soft Tissue	The soft tissue point perpendicular to the bony point, at the deepest curvature of the soft tissue.
G	Glabella	Bony	The anatomical point located at the most anterior midline point on the frontal bone marked by a smooth prominence of bone just above the naso-frontal suture (Clement & Ranson 1998), the point at the greatest anterior curvature of the bony prominence (Aulsebrook *et al.* 1996).
		Soft Tissue	The point of the most anterior soft tissue convexity of the soft tissue and underlying bony prominence, most perpendicular to the bony point (Aulsebrook *et al.* 1996) lying between the eyebrows (Işcan & Steyn 2013).
N	Nasion	Bony	The anatomical point midline of the naso-frontal suture, where the intranasal and frontonasal sutures intersect (Aulsebrook *et al.* 1996; Clement & Ranson 1998).
		Soft Tissue	The midline point of the crease between the two upper eyelids, also called sellion (Aulsebrook *et al.* 1996), midline of the nasal root and nasofrontal suture (Işcan & Steyn 2013).

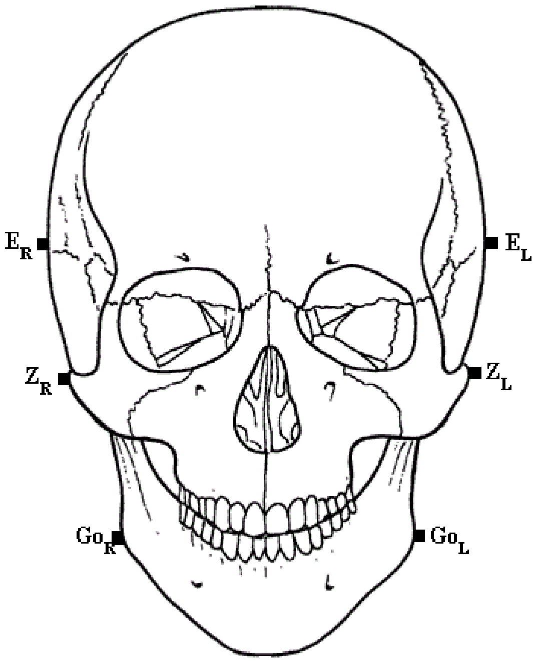


Figure 3.1: Anterior-posterior view of the bony landmarks. L indicates the left hand side and R indicates the right hand side.

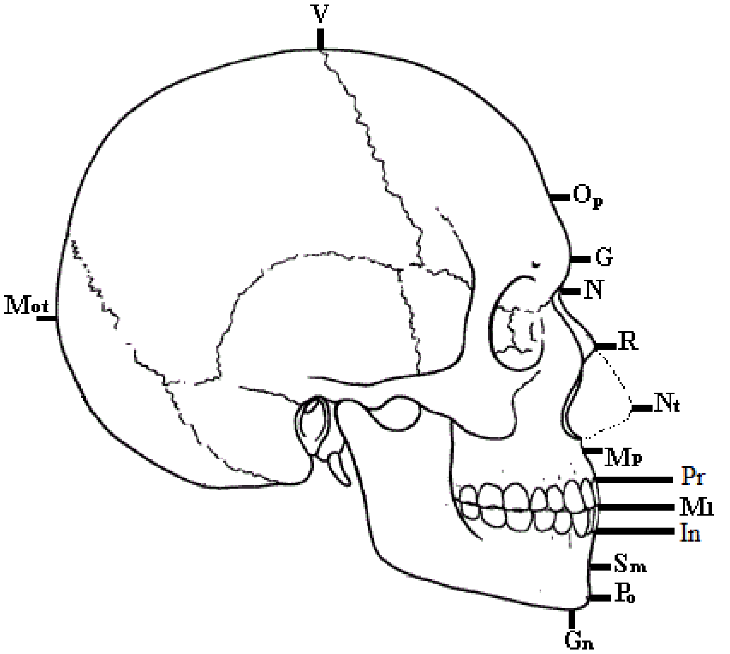


Figure 3.2: Lateral view of the bony landmarks

3.2.2. LODOX® STATSCAN

3.2.2.1. RADIOGRAPHY AND ITS USE IN MEASURING FACIAL SOFT TISSUES

Ionizing radiation is found in natural and manmade objects (Irving *et al.* 2008). X-radiation (X-rays) is a form of electromagnetic radiation that can penetrate through objects to create images of them. The X-rays are emitted by a source and pass through the body of the individual or object, attenuated depending on the density of that body, which then illuminate the detection device (Beets 2007). The different densities of the body result in the image seen. Different methods of radiography are used to produce images for different purposes.

In this study the LODOX® Statscan was used to produce X-ray images to measure the soft tissue thicknesses of cadavers and the participants. It was chosen as the radiographic method for this study as it was accessible and produced low levels of radiation exposure. This was important as live participants were sampled. Live participants were used as cadaveric measurements have been found to be larger than those from living participants (Stephan & Simpson 2008) and post-mortem changes, even those immediately following death, can affect the composition of the soft tissue (Tilotta *et al.* 2009; Wilkinson 2010).

3.2.2.2. DISTORTION FROM X-RAYS

Ideally, radiography allows for the comprehensive evaluation of areas of the body without using invasive means (Beningfield *et al.* 2003). It is necessary to be able to take accurate measurements from radiographic images, for medical as well as forensic applications.

This is complicated by the non-linear distortion radiographic images possess (Beets 2007) which necessitated the two stage process in this study. One method of accounting for the distortion is using a metal ruler in the image and, with its known measurements, using it to create a scaling factor which allows for measurements to be inferred from the image (Beets 2007). This is the method which was used in this study.

The X-rays beam from a source and spread out before they are captured by a detection device, like a photographic plate, film or electronic CCD sensor (Beets 2007). The sharpness of the image is affected by the source image distance (SID) and the object image distance (OID). The shorter the SID, the greater the divergence angle of the X-ray beams and the greater the distortion. The closer the OID is, the smaller the distortion of the image that occurs, due to peripheral X-rays diverging less from the central ray. Having receptors immediately adjacent to the body being scanned increases the image sharpness and decreases the distortion (Stull *et al.* 2013). Essentially, objects closer to the centre of the beam are more accurately imaged but those closer to the edges are distorted (Beets 2007; Stull *et al.* 2013).

The LODOX® Statscan was used in this study; it has a SID of 130cm, which is greater than the current standards and aids in decreasing distortion. The table surface is around 6cm from the detector for the minimum OID, which further decreases distortion of the images (Stull *et al.* 2013) conventional radiographic machines use cone which creates distortion in both the perpendicular and horizontal directions, while the LODOX® Statscan uses fan beam, which allows for distortion only in the perpendicular direction along the beam width (Beets 2007; Stull *et al.* 2013).

The LODOX® Statscan machine is a FDA approved digital X-ray machine with low dose radiation exposure that provides rapid full-body anterior and lateral views, based on enhanced linear slot scanning technology. It uses around 10% of the mean conventional radiation (Evangelopoulos *et al.* 2010; Tabbara *et al.* 2011), which is a boon of this type of X-ray as there is a need to reduce the amount of radiation exposure experienced by patients and medical service individuals as use of radiographic imaging increases (Irving *et al.* 2008).

The machine consists of a rotating anode X-ray tube and a source mounted on a C-arm, which emits an adjustable low-dose collimate fan-beam of X-rays, of widths 0.4 or 1.0mm. (Beningfield *et al.* 2003; Beets 2007; Irving *et al.* 2008). On the end of the C-arm is the detector unit, which comprises of scintillator arrays optically linked to charge-coupled devices. The C-arm is capable of rotating axially around the body being imaged, up to and including 90 degrees. It allows for a horizontal beam through lateral, oblique and erect views. It is also enabled to move linearly while scanning (Beningfield *et al.* 2003; Beets 2007; Tabbara *et al.* 2011).

The C-arm can travel at 138mm/s, which allows for rapid imaging. A full-body scan can take a total of 13 seconds, less if imaging only parts of the body (Beningfield *et al.* 2003; Tabbara *et al.* 2011). The LODOX® Statscan does not use film but is fed directly to computer where the x-ray image is immediately available for analysis via conventional computer systems (Tabbara *et al.* 2011).

The LODOX® Statscan is computer operated, allowing rapid acquisition of digital images with standard digital imaging and communication in medicine three output (Beningfield *et al.* 2003). It can produce images up to 1800 x 680mm^2 in size, with a fundamental pixel size of 60u and a contrast resolution of 14-bit greyscale. The spatial resolution can be as high as 15 linepairs/mm depending on the image settings (Stull *et al.* 2013).

The images are immediately available via conventional computer systems. The images are accurate, reliable, with relatively high sensitivity and specificity which has made them of particular use in trauma care. However, LODOX® Statscan images are not as high resolution as those from CT scan of MRI (Tabbara *et al.* 2011).

It was developed in South Africa for use in the diamond mines to detect hidden diamonds (Tabbara *et al.* 2011). The LODOX® Statscan has many positives for its use in research, mainly its speed and low dose radiation. The name LODOX® itself stands for Low Dose X-ray. A study by Beningfield *et al.* (2003) found that the total radiation from a full-body scan was 0.034 roentgen, 5.9% of the polydoros dose. This means that the radiation exposure from the LODOX® Statscan is less than from conventional radiographic methods. The mean dose from the LODOX® Statscan was 0.033R (0.33mGy), 5.9% of conventional radiographic means. This is much lower than from CT scans, where radiation dosage is comparable to over 1000 conventional radiographs (Winslow *et al.* 2008).

The length of exposure for a LODOX® Statscan is 13 seconds for a full body scan (Tabbara *et al.* 2011) - the less time spent in exposure further reduced the risk to the volunteers. With the need to only image the head, the exposure time was even further decreased.

A LODOX® Statscan machine is located in room 7.13, floor seven of the Anatomy Building, the Department of Human Biology, on the University of Cape Town’s Health Sciences Faculty. It was therefore conveniently located for the researcher and the participants to access.

The LODOX® Statscan was used because of its low-dose radiation in comparison to other radiographic methods. In comparison, Winslow *et al.* (2008) showed that CT scans ionizing radiation can increase lifetime cancer risk. LODOX® is also faster (Evangelopoulos *et al.* 2010; Beningfield *et al.* 2003) and the images are “substantially equivalent to that of regular x-rays (Beningfield *et al.* 2003) and “provide similar quality ... to that of CT scans” (Chen *et al.* 2011).

3.2.3. ASSESSMENT OF 3D MEASUREMENTS COMPARED TO RADIOGRAPHIC MEASUREMENTS

A LODOX® Statscan certified technician operated the machine as the researcher was not qualified to run the equipment on the living participants.

3.2.4. ETHICS

The Human Research Ethics Committee of the University of Cape Town granted permission for this study to be performed (499/2012), with the provision that all participant information gathered during the course of this study remain anonymous. Participant names and data numbers were recorded on the Information and Consent Forms (Addendum A) and will remain property of the author alone.

Any data reported in any journal or scientific publication will not contain any information that may identify a participant in this study.

3.3. COMPARING 3D MEASUREMENTS TO RADIOGRAPHIC MEASUREMENTS

3.3.1. INTRODUCTION

To determine whether LODOX® statscan images were acceptable substitutes for physical tissue depth measurements, 15 cadaver heads from the University of Cape Town's Health Science Faculty were LODOX® imaged. The heads were scanned in two positions, anterior-posterior and lateral, and held in place using paper towelling and heavy plastic blocks. Care was taken not to compress the tissues with the blocks during scanning so as not to distort the measurements. The paper towelling did not interfere with the outlines of the tissues in the LODOX® images.

A metal ruler was imaged with the cadaver heads to include a scale of known length which could later be measured using a digital program. This known length was then used to determine the scale of the images.

3.3.2. LODOX® STATSCAN MEASURMENTS OF CADAVERS

Measurements of the set facial landmarks were taken from the LODOX® Statscan images using the program ImageJ (http://imagej.nih.gov/ij/), an image processing program. The scale of the LODOX® images was measured using the Straight Line Tool in the program. The image was magnified so the image of the scale of the metal ruler was clearly visible and measured, then using the program function of Set Scale, the known length of 1cm was recorded and set for the whole image.

The bony landmarks were identified on the LODOX® images of the cadaver heads. The landmarks were then measured by drawing a perpendicular line between the bony landmark and the tissue surface with the Straight Line Tool. This length was considered to be equivalent to the soft tissue thickness at that landmark. Measurements were performed for each landmark and repeated three times each, on a varying rotation of the landmarks. The average of these three measurements was then recorded for use in statistical analysis.

3.3.3. PHYSICAL SOFT TISSUE MEASUREMENTS OF CADAVERS

Physical tissue depth measurements were taken from the same 15 cadaver heads using the needle puncture technique (Krogman 1962) - a technique whereby a mechanism consisting of a needle and stopper are used to measure tissue depth.

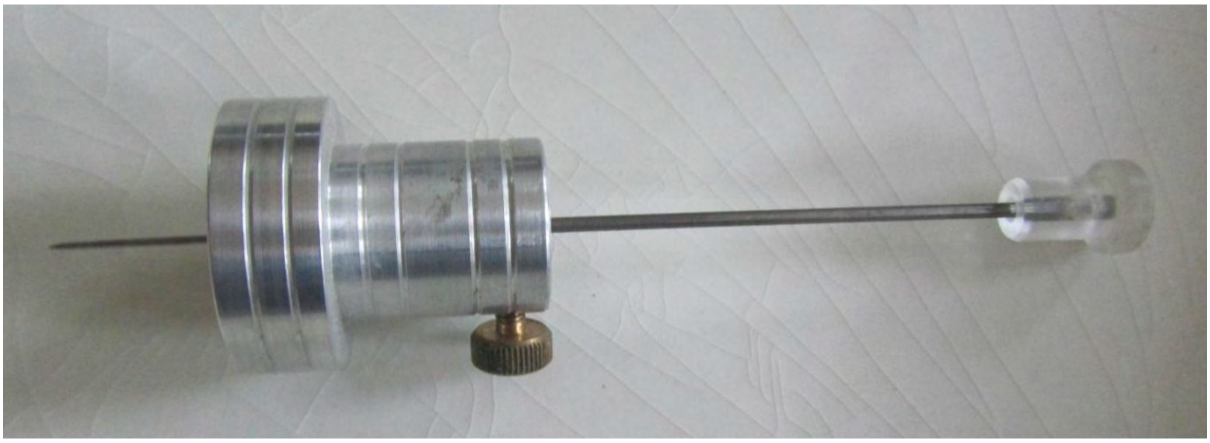


Figure 3.3. Mechanism used to measure tissue depths of cadaver heads

For Stage 1 of this study a mechanism was constructed (Figure 3.3) with a known total length of 120mm. The needle was inserted through the skin of the cadaver at the set landmarks until bone was reached. The large stopper was moved down the shaft of the needle until it reached the skin's surface, then secured in place by the turning the screw to tighten it against the needle so it would not move during extraction. The mechanism was then extracted from the tissue and the length of the needle remaining above the stopper measured using callipers. This measurement could then be subtracted from the total length of the needle to calculate the tissue depth.

Tissue Depth Measurement= 120mm- Calliper measurement

Measurements at each landmark were taken three times each, in a varying cycle of the landmarks, and the results averaged. These results were then tabulated and statistically analysed to determine if there was a significant difference between tissue depth measurements taken from physical soft tissues and measurements taken from the LODOX® Statscan images.

3.3.4. ANALYSIS OF PHYSICAL AND RADIOGRAPHIC MEASUREMENTS

Initial analysis used measurements taken from the LODOX® Statscan images to the nearest 0.01 cm, as described in Chapter 3.3 Materials and Methods. A total of 15 cadaver heads were imaged for this purpose. The descriptive statistics are summarised in Table 3.2.

It was not possible for some measurements to be taken, this was due to a number of reasons. In some cases the process whereby the head of the cadaver was removed from the body damaged the area of interest, as was the case for the Maximum Occipital Point. In other cases, the preservation process had distorted the soft tissues and made them difficult to measure, such as with Gnathion. Difficulty in measuring the distorted tissues was made greater as the age of the cadavers meant that most displayed resorbed bone, missing teeth or other age-related changes, particularly in the oral region of the face. Therefore the landmarks for Mid-philtrum and Midlip were not measured.

Of the 15 landmarks, 17 were possible to measure on the cadaveric sample. The landmarks for Euryon, Zygion and Gonion, which were taken of both the left and right sides, were averaged into a single measurement for each landmark. This left 14 landmarks which were analysed using the statistical program STATA.

3.3.5. RESULTS OF ANALYSIS

3.3.5.1. DESCRIPTIVE STATISTICS OF PHYSICAL MEASURMENTS

Descriptive statistics were performed for the physical measurements data, including mean, standard deviation, maximum and minimum. The summarized results are in Table 3.2.

The smallest measurement was found at Rhinion, of 0.10cm. The next smallest measurements were Ophryon (at 0.18cm), Bregma (at 0.23cm), and Euryon (at 0.24cm). The largest measurement was nasal tip (at 3.89cm), followed then by Gnathion right (at 2.24cm) and left (at 2.42cm), and Gonion (at 2.19cm).

Nasal tip also had the greatest standard deviation (at 0.91cm) which indicated it had the greatest variation around the mean. The smallest standard deviations occurred at Glabella (at 0.12cm) and Nasion (at 0.14cm), which indicated they had the lowest variation around the mean.

3.3.5.2. DESCRIPTIVE STATISTICS OF THE LODOX® STATSCAN MEASURMENTS

Descriptive statistics were performed for the physical measurements data, including mean, standard deviation, maximum and minimum. The summarized results are in Table 3.3.

Rhinion was the smallest measurement (at 0.17cm), followed by Bregma (at 0.19cm), Euryon and Ophryon (at 29cm). Nasal Tip was the largest measurement (at 4.13), followed by Gonion (at 2.21cm). Nasal Tip displayed the largest standard deviation of 0.65, followed by Gonion (at 0.57). The lowest standard deviations were found at Rhinion and Ophryon (at 0.11), followed by Nasion (at 0.12) and Glabella (at 0.13).

Table 3.3. Descriptive statistics of the soft tissue measurements of the landmarks of the cadaver sample

Landmarks	Mean		St. Deviation		Minimum		Maximum	
	Phys	LODOX ®	Phys	LODOX ®	Phys	LODOX ®	Phys	LODOX ®
Vertex	0.58	0.69	0.28	0.29	0.23	0.19	1.23	1.13
Euryon	0.63	0.64	0.27	0.20	0.24	0.28	1.22	1.11
Zygion	0.90	0.83	0.36	0.29	0.36	0.48	1.55	1.67
Gonion	1.34	1.31	0.59	0.57	0.49	0.48	2.19	2.21
Gnathion	0.98	0.97	0.47	0.45	0.32	0.32	2.24	1.76
Rhinion	0.38	0.29	0.18	0.11	0.10	0.17	0.78	0.54
Nasal Tip	2.87	2.63	0.91	0.65	0.50	1.65	3.89	4.13
Mid-Philtrum	1.01	1.06	0.52	0.43	0.26	0.55	1.71	1.72
Supra-mentale	1.18	1.25	0.32	0.33	0.67	0.69	1.82	1.88
Pogonion	1.02	1.18	0.49	0.38	0.44	0.37	2.05	1.74
Ophryon	0.44	0.48	0.16	0.11	0.18	0.29	0.76	0.73
Glabella	0.54	0.55	0.12	0.14	0.34	0.35	0.85	0.89
Nasion	0.54	0.54	0.14	0.12	0.27	0.36	0.79	0.72

3.3.5.3. STATISTICAL ANALYSIS OF THE TWO DATA SETS

The P-values were calculated for Wilcoxon sign-rank test (the non-parametric equivalent for a matched-pairs T-test), and are displayed in Table 3.4. All landmark pairs were found to be above the standard 0.05, and thus considered not to be significantly different from each other.

Table 3.4 P-values of the soft tissue measurements of the landmarks of the cadavers sample

Measurement	P-value
Bregma	0.060
Euryon (Right)	0.053
Euryon (Left)	0.053
Zygion (Right)	0.140
Zygion (Left)	0.293
Gonion (Right)	0.776
Gonion (Left)	0.140
Gnathion	0.842
Rhinion	0.152
Nasal Tip	0.069
Acanthion	0.638
Mid-Philtrum	0.333
Supra-mentale	0.331

Pogonion	0.221
Ophryon	0.182
Glabella	0.256
Nasion	0.712

3.3.6. CONCLUSION

As all of the landmarks were found to be comparable, it was determined that measurements taken from LODOX® Statscan images would be acceptable substitutes for physical soft tissue measurements, and acceptable for use in measuring the soft tissue depths of living participants.

3.4. LIVING PARTICIPANT DATA GATHERING

3.4.1. INTRODUCTION

To determine whether facial tissue thickness is due to body fatness, 67 volunteers from the University of Cape Town's Health Science Faculty were LODOX® imaged and had physical measurements taken.

3.4.2. PARTICIPANT INFORMATION AND DATA GATHERING

Participants received a data number and an Information and Consent form (Addendum A) which informed them of the purpose of the study, the LODOX® Statscan and what measurements would be taken. The data number was used to ensure the anonymity of the participants, their LODOX® images and their physical measurements.

Participants were LODOX® scanned in the same two positions as used in Stage One of the study, anterior-posterior and lateral, by the LODOX® technician. The images were labelled with the participant data number and either Lat (for lateral) or AP (for anterior-posterior), depending on the scanned position, then transferred to the researcher for measuring. A metal ruler was imaged with the particpants to include a scale of known length which could later be measured using a digital program. This known length was then used to determine the scale of the images.

Participants also received a Volunteer Data Card (Addendum B) on which they self-identified their sex, age and population group as defined by Statistics South Africa: Census (2011). Their data number was also written on the data card to connect it with their LODOX® images whilst retaining participant anonymity.

3.4.3. ASSESSMENT OF BODY FAT OF PARTICIPANTS

Six physical measurements were taken from participants by the researcher. Weight, in kilograms, was measured using an electronic scale and height, in metres, was measured using a portable stadiometer.

The BMI was then calculated using the formula (Centers for Disease Control and Prevention 2014):

$$\text{BMI} = \text{weight (kg)} / [\text{height (m)}]^2$$

Four skinfold thickness measurements were taken using skinfold callipers. These were performed in a similar manner as described by Durnin and Womersley (1973) where measurements were taken from the right side of the participant, who was standing in a relaxed position. The four skinfold sites and their definitions according to Lohman, Roche & Martorell (1991) and Lohman (1992) are summarized in Table 3.5 and Figure 3.4.

Only one side was measured as there was no statistical difference between measurements on either side of the body as determined by Womersley and Durnin (1973). Measurements were repeated three times in a varying pattern and the average of these measurements was then recorded for statistical analysis.

Table 3.5 Defined skinfold sites as used by Durnin-Womersley Calliper Method (1973) and defined by Lohman, Roche & Martorell (1991) and Lohman (1992)

Skinfold	Definition
Subscapular	The fold is taken on the diagonal line, just inferior to the inferior angle of the scapula
Triceps	The fold is taken in the midline, over the triceps muscle.
Biceps	The fold is taken over the biceps muscle, vertically.
Suprailiac	The fold is taken immediately superior to the iliac crest, along the midaxillary line.

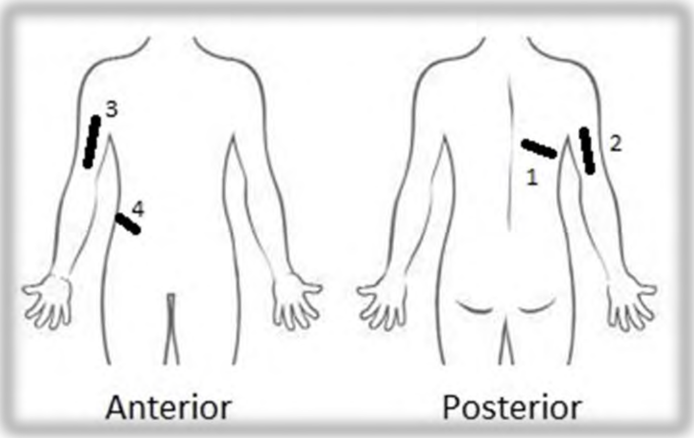


Figure 3.4 The four sites of the Durnin-Womersley Calliper Method (1973) for determining body fat percentage. 1. Subscapula, 2. Triceps, 3. Biceps and 4. Suprailiac.

These measurements were used for the Durnin-Womersley Calliper Method (1973) for determining body fat percentage from skin fold thicknesses. This method uses the least number of skin folds to measure body fat (Lohman, Roche & Martorell, 1991) and was the least invasive, required few measurements and would be the least uncomfortable for participants. For the comfort of the participants, all measurements were taken in a private room, behind a privacy screen, with only the researcher and participant present. Many participants expressed that they were comfortable with the procedure as they were familiar with the researcher from their dissection classes. Participants were encouraged to ask questions and discuss what had interested them in participating in the study with many stating their interest in forensic sciences, fitness and in seeing their own LODOX® images.

The calculation used the log of the sum of the four skinfolds, substituted into the equation used to calculate density, depending on the individual’s sex and age (Table 3.6). The equation was determined by Durnin and Womersley (1973) from the regression analysis of their study

Table 3.6 The equation to calculate density using the Durnin-Womersley Calliper Method (1973): D= C-M(L)

D = calculated density of the body (g/ml), C= constant, M= gradient and L = log of the total of the 4 skinfolds (mm)

Age	Male		Female	
	C	M	C	M
17-19	1.162	0.063	1.1549	0.0678
20-29	1.163	0.0632	1.1599	0.0717
30-39	1.1422	0.0544	1.1423	0.0632
40 -49	1.1620	0.07	1.1333	0.0612
> 50	1.1715	0. 779	1.1339	0.0645

Then using the Siri Equation (Siri, 1961) the percentage of body fat was calculated by substituting the previously calculated body density into the equation,

$$\text{Body Fat Percentage} = (495 / \text{Body Density}) - 450.$$

The Siri (1961) equation is a commonly used means of determining corporeal density. It was based on measurements taken from a sample of males of White ancestry, which does not account for all possible sex an ancestry variation. It was used in this study as it was the means of determining density used in the Durnin-Womersley Calliper Method (1973) and the mixed ancestry of the Coloured ancestry group included White ancestry.

3.4.4. LODOX® SCANS AND MEASUREMENTS

The scale of the LODOX® images was measured using the Straight Line Tool in the program ImageJ. The image was magnified so the image of the scale of the metal ruler was clearly visible and measured, then, using the program function of Set Scale, the known length of 1cm was recorded and set for the whole image. In the cases where the metal ruler was not included in the image, the average of the total of each scale measurement was used.

Measurements were taken by drawing a perpendicular line between the bony landmark and its corresponding soft tissue landmark (Refer to Chapter 3.2. 1 Facial Bony Landmarks and Associated Measurements) with the Straight Line Tool. This length was considered to be equivalent to the soft tissue thickness at that landmark. This was performed for each landmark and then repeated three times for each. The average of these three measurements was then recorded.

The landmarks for Euryon, Zygion and Gonion, which were taken of both the left and right sides, were averaged into a single measurement for each landmark.

3.4.5. ANALYSIS OF THE RADIOGRAPHIC IMAGES AND ASSOCIATED MEASUREMENTS

Descriptive statistics were performed for each variable, including the mean, the average of the values; median, the middle value; standard deviation, the values of how much the other values differ from the mean; minimum, the lowest value; and maximum, the highest value.

A Shapiro-Wilk test was used to test whether data for each variable was normally distributed.

Regression analysis was performed on the parametric variables, while Spearman Rank Correlation was performed on the non-parametric variables. Regression analysis was performed to determine which of the landmark measurements showed the greatest change as body fat percentage and BMI increased. It also allowed for graphs to visually demonstrate these changes and to determine which changes were significant and which were the result of chance.

Outliers were defined as those values that were perceived as different and to lie outside the range of the other values, not falling within the larger grouping or shape of the other values. They were kept as part of the sample during analysis because of the small sample size of this study and because they are representative of the human variation being described in this study.

With height and weight measurements, the BMI for each participant could be calculated (Chapter 3.4.3 Assessment of Body Fat of Participants) and used to separate the data into 2 groups. The point of separation was 25, which is considered to be the end of the normal range for weight status (Centers for Disease Control and Prevention 2014).

The data were also divided by sex and the population groups. Due to the small number of Black African and Coloured participants and their genetic similarities (Cavanagh & Steyn 2011), the two ancestry groups were combined for statistical analysis.

A T-test was then applied to determine for which landmark measurements there was a significant difference between the means of the BMI groups, sexes and ancestry groups. The sequential Bonferroni method was applied to the p-values to determine account for the increased chances of incorrect significant results from multiple tests.

The coefficients of variation were calculated to determine how the landmarks relate to each other. During facial reconstruction the practitioner would need to take into consideration the relationships between the different landmarks and their soft tissues. The coefficient of variation is useful as it dimensionless and can be used to compare data with different units and different means.

A Levene's F test was used to compare the magnitudes of variation, the homogeneity of variance, and determined whether the differences of the means were actually significant ($P< 0.05$). The Levene's F-test of significance were calculated for the total sample, the sex and the ancestry groups; for the sample divided by sex, BMI group and body fat percentage group. BMI was divided at the point of 25kg/m^2, the cut-off between normal and overweight BMI (Centers for Disease Control and Prevention 2014). Body fat percentage was divided at the point of 25% for males and 32% for females, the cut-offs between normal and overweight BMI (Muth 2009).

4. RESULTS

4.1. DESCRIPTIVE STATISTICS OF TOTAL SAMPLE

Descriptive statistics were performed for each variable; including the mean, standard deviation, maximum, and minimum. Table 4.1 summarizes the results.

In this study 67 participants took part.

Males and females had similar ranges for age, with the volunteers being recruited from the student population of the Health Sciences Faculty of the University of Cape Town. Females were of the youngest and oldest ages, 18 and 50 respectively.

Table 4.1. The descriptive statistics of the participant data.

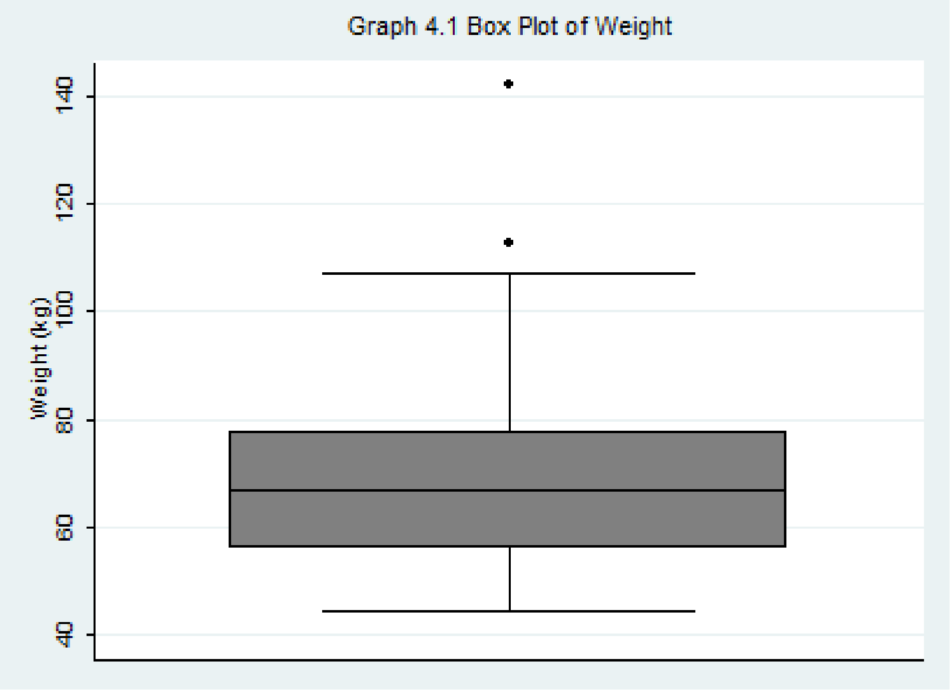
Measurements	n	Mean	Median	St Dev.	Max	Min
Age (years)	67	23.2	22	5.6	50	18
Height (cm)	67	166.4	165.6	8.4	185.6	148.7
Weight (kg)	67	69.8	66.9	17.2	141.8	44.3
BMI (kg/m$^{2)}$	67	25.2	23.9	5.6	42.0	17.2
Biceps	67	9.2	7.1	5.9	30.5	2.5
Triceps	67	21.1	19.0	9.4	46.0	4.6
Subscapular	67	14.8	14.2	6.5	43.2	5.8
Supra-iliac	67	14.7	14.2	6.6	33.9	2.0
% Fat	67	26.6	27.1	7.5	40.7	7.8

4.2. ANALYSIS OF WEIGHT, BMI AND BODY FAT PERCENTAGE

4.2.1. CORRELATION WITH WEIGHT

The relationship between weight, BMI and body fat percentage was analysed. Weight is used to calculate BMI, using the formula (kg) / [height (m)]^2 (Centers for Disease Control and Prevention).

There were two outliers, shown by Graph 4.1. The first, at a weight of 112.80kg, was a Black African female, and the second an extreme outlier, at a weight of 141.80kg was a White male. The mean weight was 69.85kg, with the first quartile at 56.55kg and third quartile at 77.45kg, with an interquartile range of 20.9kg.

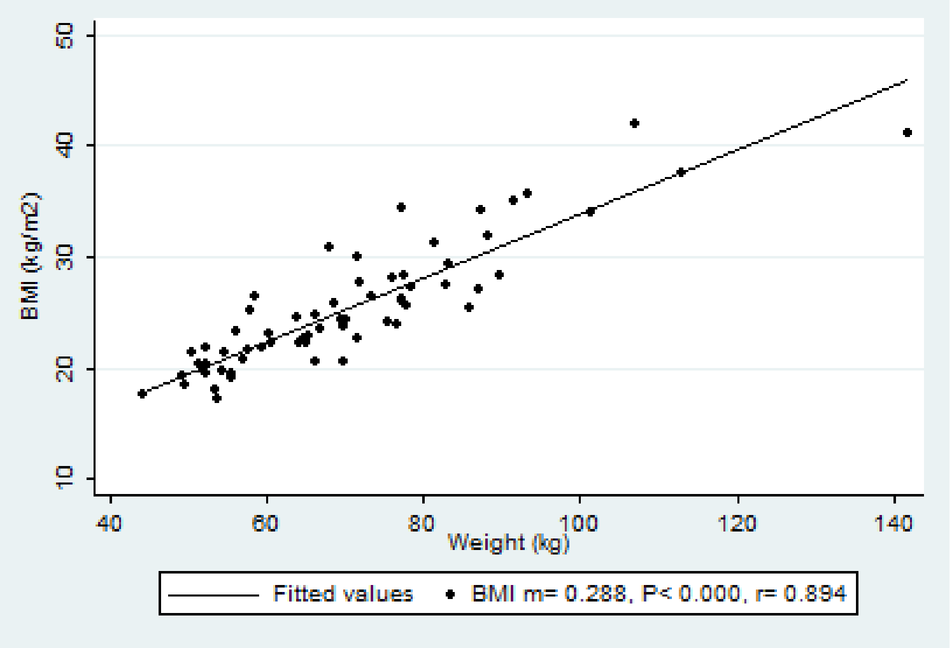


4.2.2. CORRELATION OF BMI AND BODY FAT PERCENTAGE

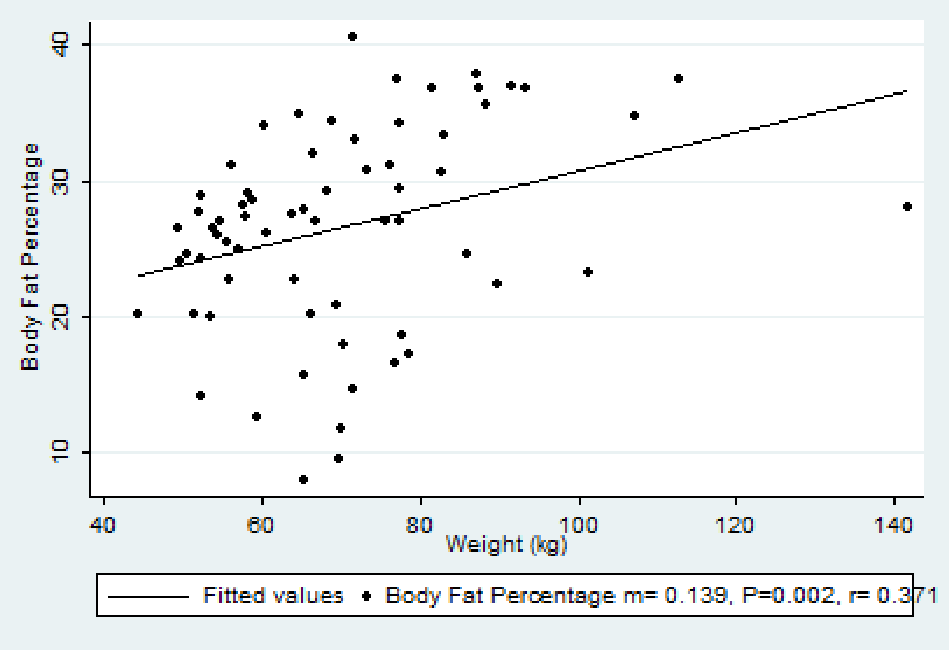
As weight is used to calculate BMI, Graph 4.2 shows that BMI is significantly correlated to weight. The correlation coefficient (r= 0.894) was high and from the graph it can be seen that the correlation is high.

In comparison, weight is not used to calculate body fat percentage and Graph 4.3 demonstrates that while there is a significant relationship between the two factors, the correlation is not as high as with BMI. The spread of the points is greater for body fat percentage than BMI.

Graph 4.2 Correlation of BMI over Weight

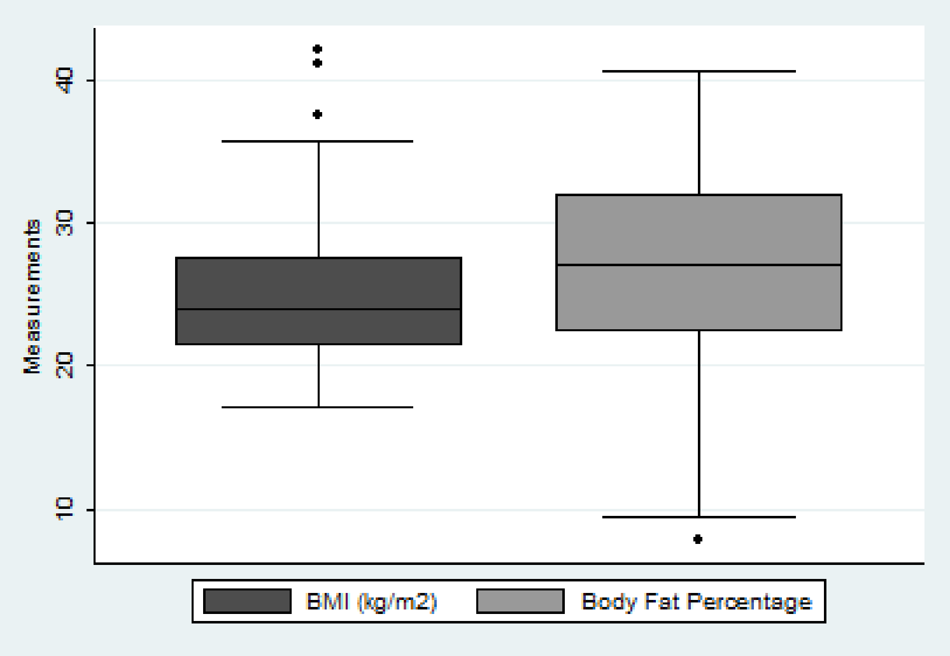


Graph 4.3 Correlation of Body Fat Percentage over Weight

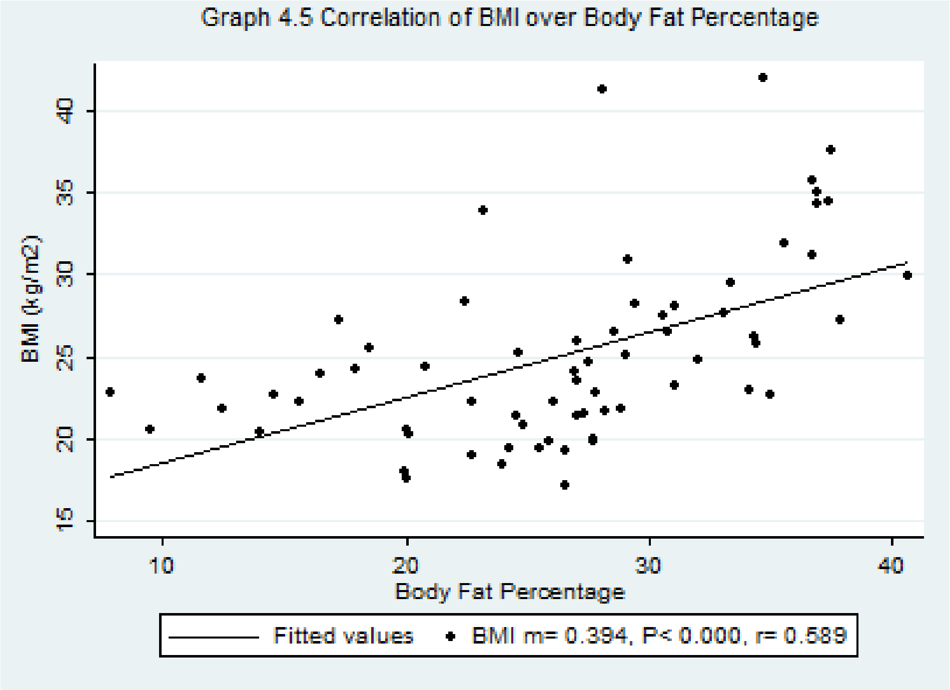


BMI and body fat percentage were then analysed as the two main means of determining participant fatness. Graph 4.4 shows the distribution of BMI and body fat percentage. The first quartile for BMI is 21.39kg/m^2, the third quartile 27.57 kg/m^2 and the inerquartile range 6.18 kg/m^2. The first quartile for body fat percentage is 22.56%, the third quartile 31.56% and the interquartile range 9.00%. There were three mild outliers for BMI and one for body fat percentage. Of the three outliers for BMI, 2 were the same participants as in Graph 4.

Graph 4.4 Box Plots of BMI and Body Fat Percentage



Graph 4.5 shows BMI correlated to body fat percentage, which had an r-value of 0.589 and was significant (P< 0.000).



Graph 4.5 Correlation of BMI over Body Fat Percentage

This indicated for this study there was a significant relationship between the two measures of fatness. The r-value indicated that there was a moderate positive correlation. The outliers are the same as seen in Graph 4. 4.

With an r-value of 0.894, BMI has a stronger relationship with weight than with body fat percentage, which has a stronger relationship with BMI than weight (r= 0.371).

4.2.3. BMI CORRELATION WITH BODY FAT PERCENTAGE FOR SEX

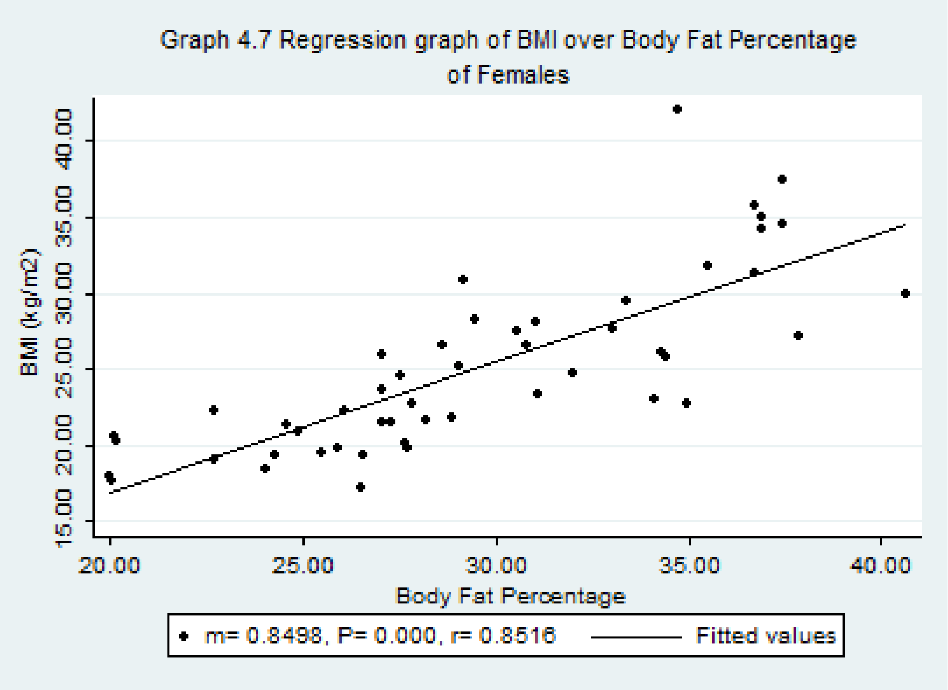
Graph 4.6 shows how BMI correlates with body fat percentage for the sexes with males and females plotted separately, with separate regression lines.

There are 2 clusters, separated by sex. The majority of males have lower body fat percentages for the same BMI as females. When males and females have similar BMI, females tend to have a higher body fat percentage.

Looking at the regression lines, as BMI increases, the body fat percentages move towards each other slightly.

4.2.3.1. FEMALES

Graph 4.7 shows BMI correlated to body fat percentage for females, which had an r-value of 0.8516 and was significant (P< 0.001).



This indicated for this study there was a significant relationship and the r-value indicated that there was a strong positive correlation between the two measures of fatness for females.

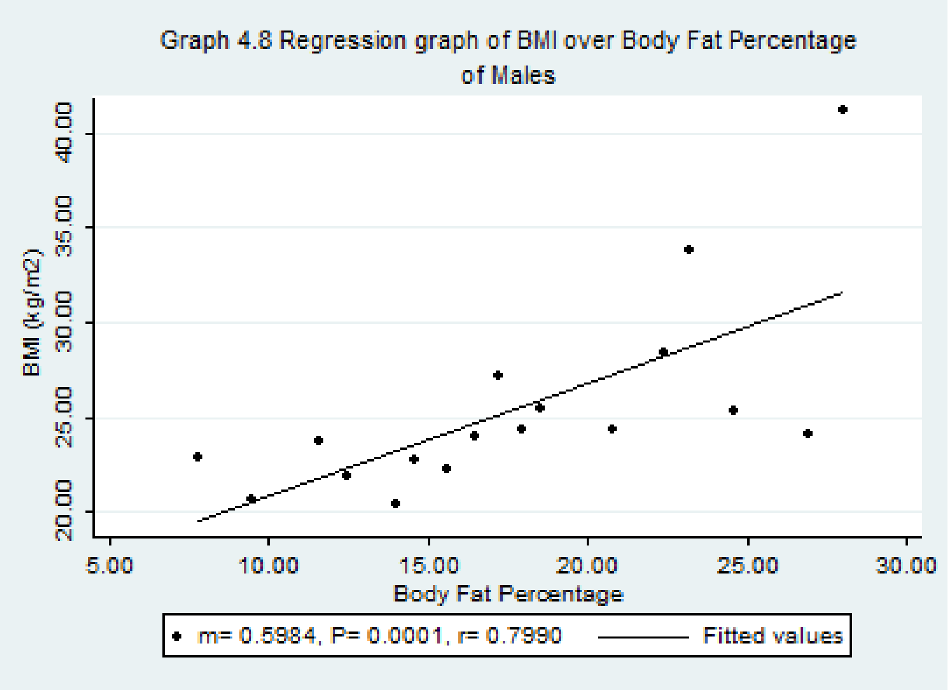
There was one outlier.

4.2.3.2. MALES

Graph 4.8 shows BMI correlated to body fat percentage for males, which had an r-value of 0.5984 and was significant (P< 0.001).

This indicated for this study there was a significant relationship, though not as strong as for females, and the r-value indicated that there was a strong positive correlation between the two measures of fatness for males.

There were two outliers.



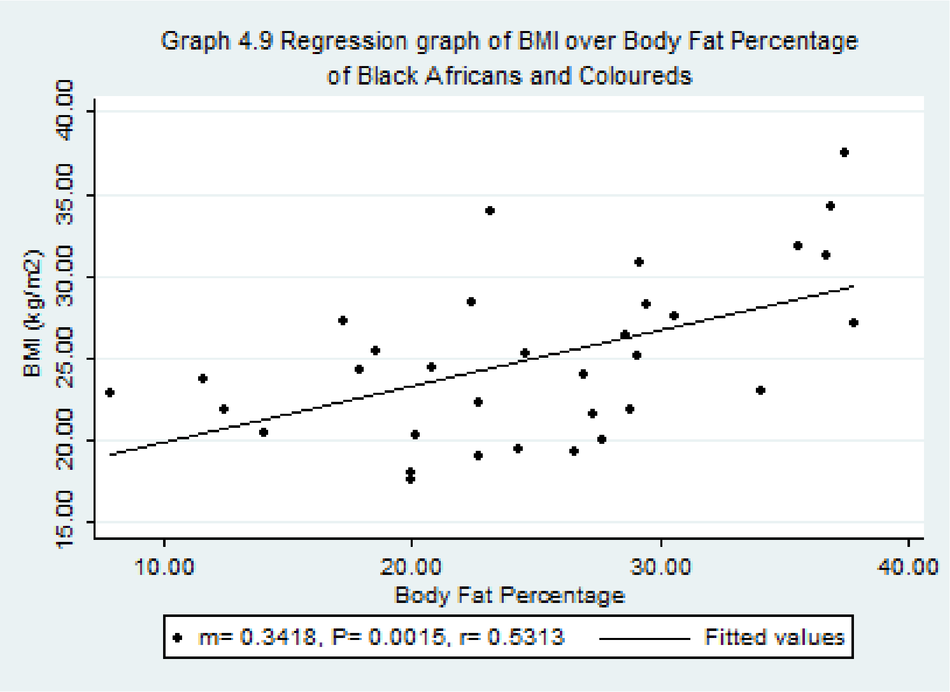
4.2.4. BMI CORRELATION WITH BODY FAT PERCENTAGE FOR ANCESTRY GROUP

4.2.4.1. BLACK AFRICANS AND COLOUREDS

Graph 4.8 shows BMI correlated to body fat percentage for Black Africans and Coloureds, which had an r-value of 0.3418 and was significant (P= 0.0015).

This indicated for this study there was a significant relationship and the r-value indicated that there was a moderate positive correlation between the two measures of fatness for Black Africans and Coloureds.

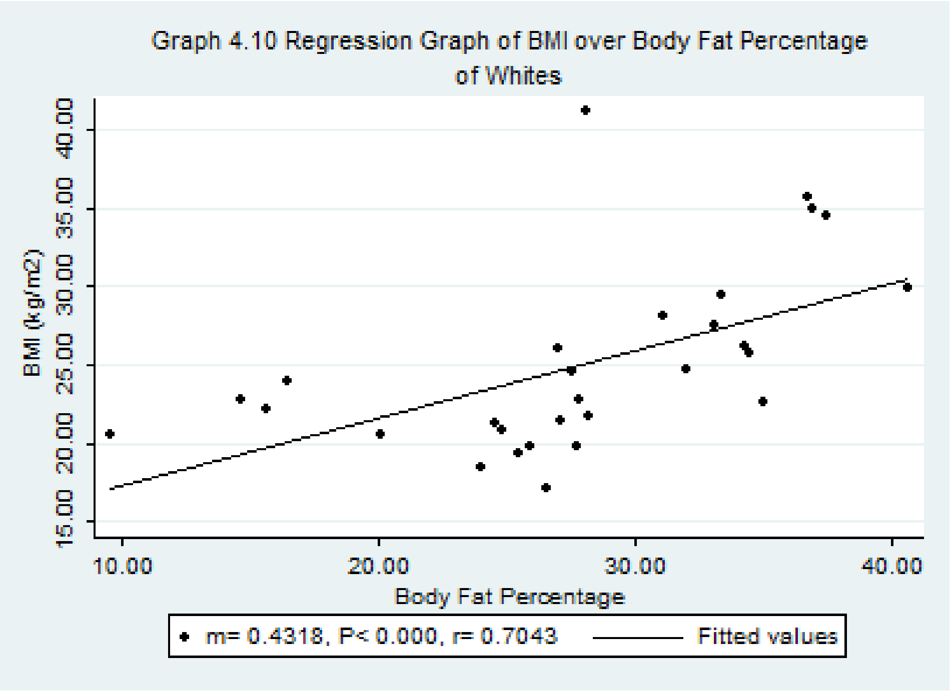
There were two outliers.



4.2.4.2. WHITES

Graph 4.9 shows BMI correlated to body fat percentage for Whites, which had an r-value of 0.4318 and was significant (P< 0.001). This indicated for this study there was a significant relationship and the r-value indicated that there was a moderate strong correlation between the two measures of fatness for Whites.

There was one outlier.



4.3. DESCRIPTIVE STATISTICS OF THE SOFT TISSUE OF THE LANDMARK MEASUREMENTS

Table 4.2 summarizes the descriptive statistics of the landmark measurements.

The landmark that exhibited the greatest standard deviation was Gonion (SD= 0.64cm), which is consistent with it having the greatest range (R= 3.30cm) and highest maximum measurement (a maximum of 4.12cm). Rhinion had the smallest standard deviation (SD= 0.1cm) and the smallest range (R= 0.48cm).

Nasal tip had the greatest mean (μ= 2.96cm) and Midlip had the lowest minimum (a minimum of 0.14cm).

Table 4.2 The descriptive statistics of the soft tissue of the landmark measurements (cm)

St Dev.= Standard Deviation, Max. Occipital Pt= Maximum Occipital Point

Landmarks	n	Mean	Median	St Dev.	Max	Min	Range
Euryon	67	0.99	0.96	0.24	1.69	0.53	1.16
Zygion	67	1.11	1.01	0.38	2.37	0.52	1.85
Gonion	67	1.57	1.41	0.64	4.12	0.82	3.30
Vertex	67	0.67	0.68	0.16	1.05	0.34	0.71
Max. Occipital Pt	67	0.87	0.82	0.19	1.41	0.54	0.87
Rhinion	67	0.31	0.30	0.10	0.63	0.15	0.48
Nasal Tip	67	2.96	2.95	0.37	3.80	2.30	1.50
Mid-philtrum	67	1.74	1.65	0.34	2.73	1.04	1.69
Prosthion	67	1.43	1.38	0.24	2.22	1.02	1.20
Midlip	67	0.58	0.60	0.22	1.12	0.14	0.98
Inion	67	1.11	1.09	0.16	1.59	0.81	0.78
Supra-mentale	67	1.47	1.44	0.24	2.33	1.01	1.32
Pogonion	67	1.01	0.98	0.29	1.68	0.55	1.13
Gnathion	67	0.87	0.79	0.37	2.13	0.43	1.70
Ophryon	67	0.65	0.63	0.13	1.14	0.46	0.68

Glabella	67	0.69	0.69	0.12	1.00	0.47	0.53
Nasion	67	0.83	0.83	0.18	1.58	0.47	1.11

It is interesting to note that from the images, there was one individual where the nose and ears would not display in X-ray, and so the associated landmarks, Nasal Tip and Rhinion, for this individual could not be measured.

4.4. REGRESSION ANALYSIS OF TOTAL SAMPLE

Table 4.3 The results of the Shapiro-Wilk tests for the factors and landmarks. Max. Occipital Pt= Maximum Occipital Point

Factors and Landmarks	P>Z
Age	0.000
Height (cm)	**0.670**
Weight (kg)	0.000
BMI	0.000
Body Fat Percentage	**0.168**
Euryon	0.022
Zygion	0.000
Gonion	0.000
Vertex	**0.832**
Max. Occipital Pt	**0.059**
Rhinion	0.005
Nasal Tip	**0.286**
Mid-philtrum	0.044
Prosthion	0.008
Midlip	**0.827**
Inion	0.004
Supra-mentale	**0.075**
Pogonion	0.022
Gnathion	0.000

Ophryon	0.000
Glabella	0.174
Nasion	0.002

The majority of landmark measurements were not parametric. Height and body fat percentage were parametrically distributed.

4.4.1. BODY FAT PERCENTAGE REGRESSION ANALYSIS

The results of regression analysis of the landmark tissue depth measurements for all participants and corresponding body fat percentages were summarized in Table 4.4. The landmarks were ordered by the descending gradient (m-value) of the best fit line.

The greater the m-value, the greater the change the tissue depth of each landmark for a percent increase of body fat.

Gonion, Zygion, Gnathion, Pogonion Ophryon and Prosthion were found to be significant with $P<0.05$, and Gonion and Zygion had the greatest r-values, at 0.549 and 0.622 respectively. Gonion, Zygion, Gnathion and Pogonion had the greatest m-values, which indicated that they were the landmarks that changed the most as body fat percentage increased.

Gonion (Graph 4.10) had the greatest gradient ($m= 0.039$), indicating that of all the landmarks it showed the greatest increase as body fat percentage increased, and the second greatest r-value ($r= 0.549$). The regression lines of Gonion, Zygion, Gnathion and Pogonion are illustrated by Graphs 4.11-14, respectively.

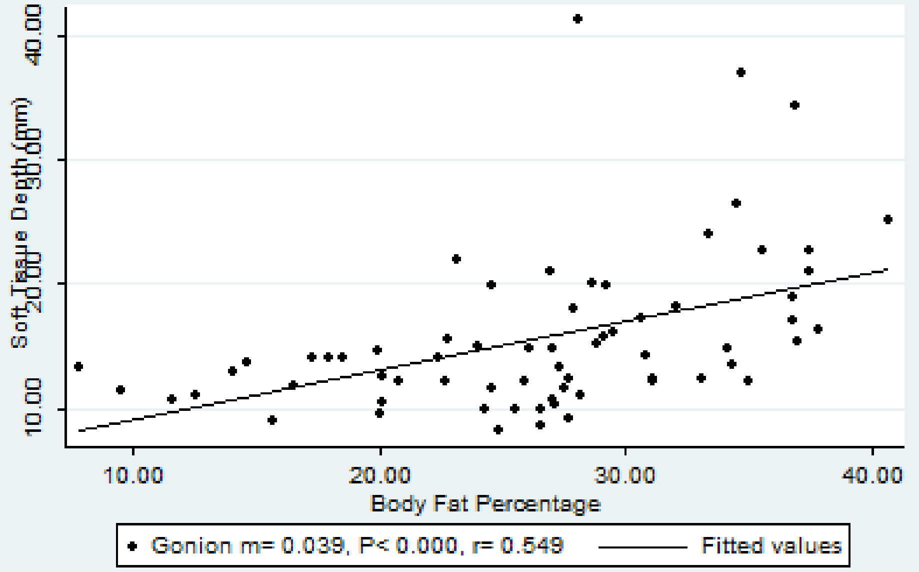
Table 4.4 Regression values of soft tissue measurements of all participants and Body Fat Percentage, ordered by gradient.

Mot = Maximum Occipital Point, m= gradient

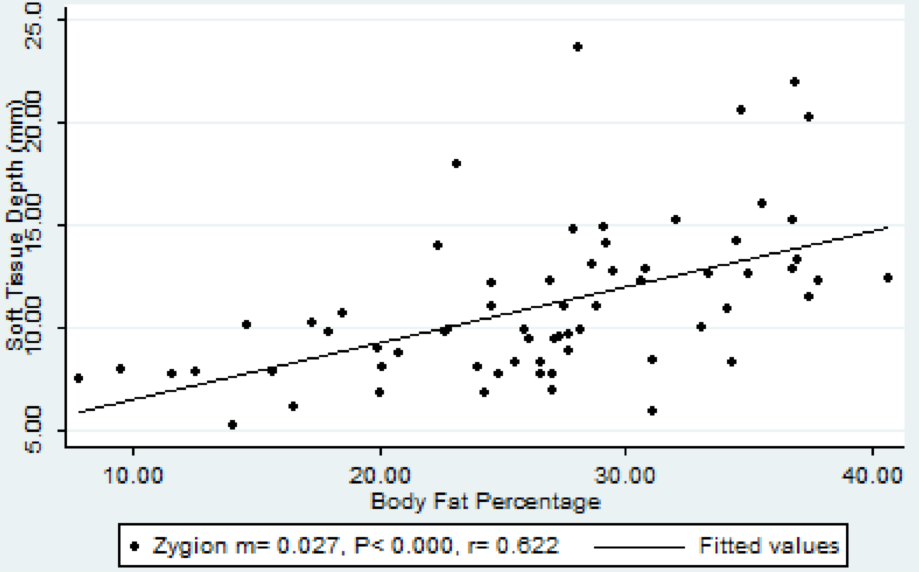
Landmarks	m-value	P-value	r-value	R-squared
Go	0.039	P< 0.000	0.549	0.301
Z	0.027	P< 0.000	0.622	0.387
Gn	0.017	0.007	0.325	0.105
Po	0.012	0.010	0.313	0.098
Mot	0.005	0.091	0.208	0.043
E	0.005	0.265	0.138	0.019
Op	0.004	0.037	0.256	0.066
In	0.003	0.132	0.186	0.035
G	0.003	0.082	0.214	0.046
Sm	0.002	0.584	0.068	0.005
V	0.002	0.451	0.094	0.009
N	0.001	0.409	0.103	0.011
R	0.000	0.903	0.015	0.000
Ml	-0.005	0.134	0.185	0.034
Nt	-0.011	0.077	0.218	0.047

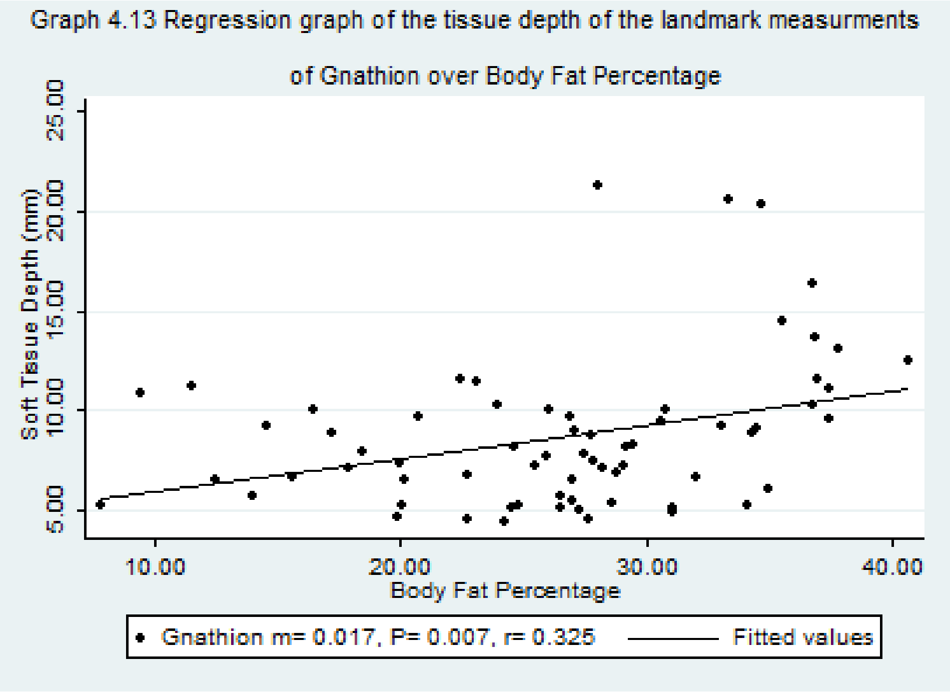
Mp	-0.011	0.156	-0.175	0.031
Pr	-0.011	0.017	-0.290	0.084

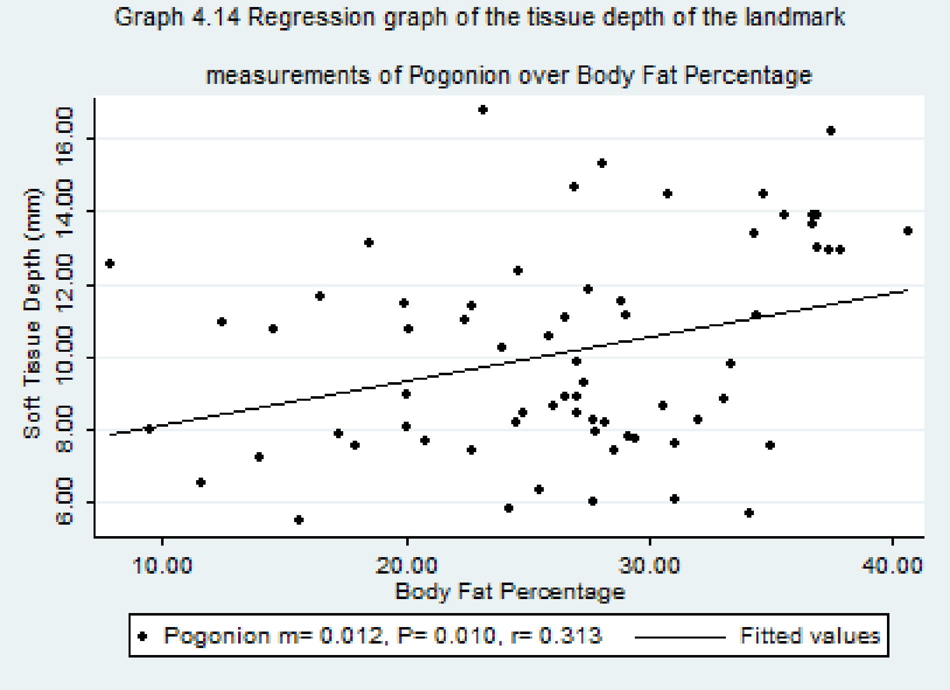
Graph 4.11 Regression graph of the tissue depth of the landmark measurements of Gonion over Body Fat Percentage



Graph 4.12 Regression graph of the tissue depth of the landmark measurements of Zygion over Body Fat Percentage




Graph 4.13 Regression graph of the tissue depth of the landmark measurments of Gnathion over Body Fat Percentage


Graph 4.14 Regression graph of the tissue depth of the landmark measurements of Pogonion over Body Fat Percentage

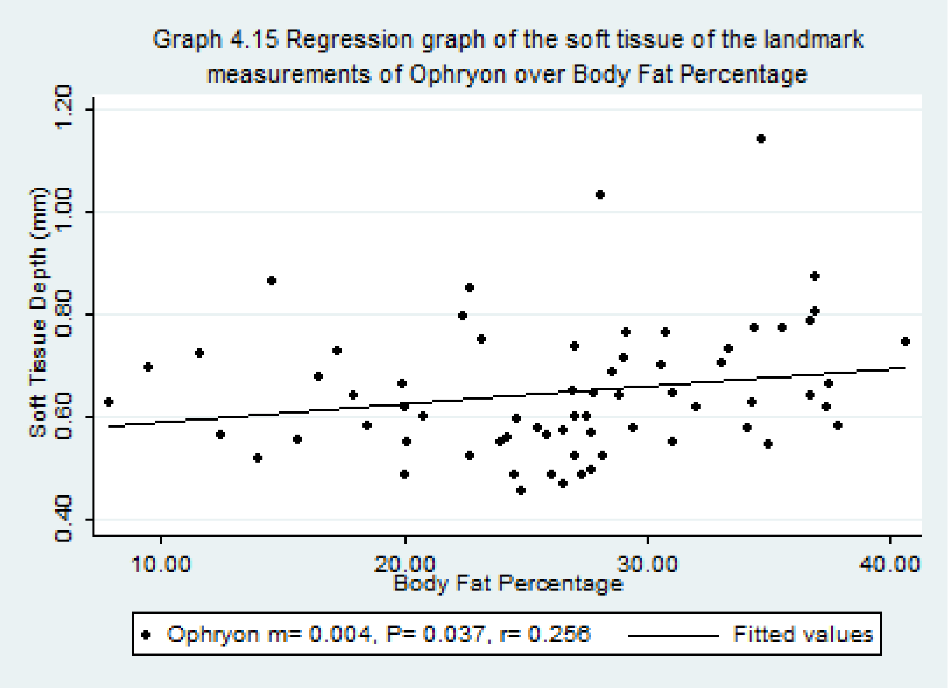
Zygion had the second greatest gradient (m= 0.27), with the highest r-value (r= 0.622), depicted in Graph 4.12. While the landmark did not show the same tissue depth change over body fat percentage as Gonion, the correlation between the fat and tissue measurements was the highest.

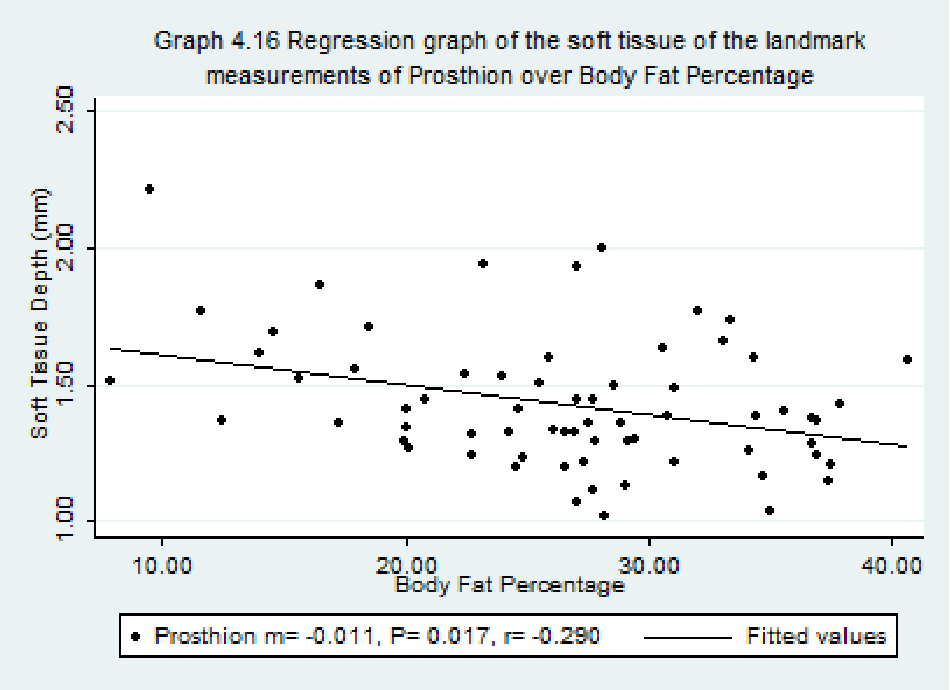
Gnathion (Graph 4.13) had the third greatest gradient of 0.017 and Pogonion (Graph 4.14) the fourth greatest gradient of 0.012. Both landmarks had weak positive linear relationships to body fat percentage, Gnathion at 0.325 and Pogonion at 0.313.

These four landmark measurements displayed the four highest positive r-values, showing that as the gradient increased, so did the correlation of the measurements to the predicted regression line. This indicated that as body fat percentage increased at these landmarks, the measurements fit closer to the predicted regression line and had greater predictability.

The other eleven landmarks showed low gradients between -0.011 and 0.006, with non-significant P-values for correlation (P>0.05).

Ophryon (Graph 4.15) and Prosthion (Graph 4.16) were the only other landmarks with significant correlations to body fat percentage. Ophryon had a low gradient (m= 0.004) and weak positive correlation (r= 0.256). Prosthion had both a negative gradient (m= -0.011) and negative correlation (r= -0.290), indicating that the tissue depth at prosthion decreases as body fat percentage increases.





Graph 4.16 Regression graph of the soft tissue of the landmark measurements of Prosthion over Body Fat Percentage

There were three outliers for Gonion, five for Zygion, three for Gnathion, two for Ophryon and one for Prosthion.

4.4.2. BMI REGRESSION ANALYSIS

The results of regression analysis of the 17 landmark measurements for all participants and corresponding BMI were summarized in Table 4.5. The landmarks were ordered in descending order by the gradient of the best fit line.

The results showed that 13 of the landmarks were significantly correlated while the highest 4 gradients were again Gonion (Graph 4.17), Zygion (Graph 4.18), Gnathion (Graph 4.19) and Pogonion (Graph 4.20).

Gonion had the greatest gradient (m= 0.090), indicating that of all the landmarks it showed the greatest increase as BMI increased. It also had a greater correlation (r= 0.739) than Zygion (r= 0.702), unlike when correlated with body fat percentage. There were no negative gradients or correlations.

Compared to the gradient values for the body fat percentage comparisons, when compared against BMI the gradient, r and R-squared values for each landmark measurements were higher, indicating that the measurements against BMI had a

higher correlation, the measurement points clustering closer together. The correlation of the measurements were significant for all landmarks but Mid-lip, Mid-philtrum, Prosthion and Nasal tip.

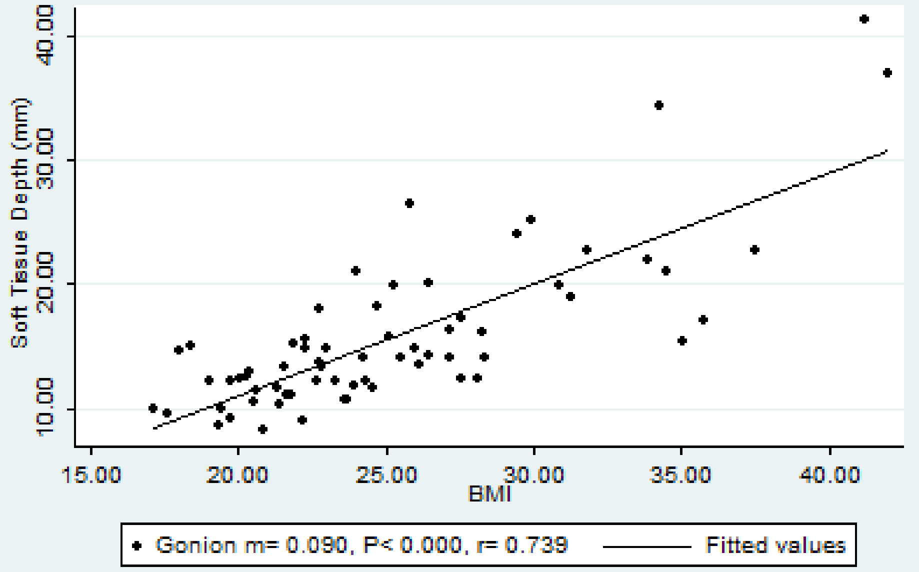
Table 4.5 Regression values of soft tissue measurements of all participants and BMI (kg/m^2), ordered by gradient.

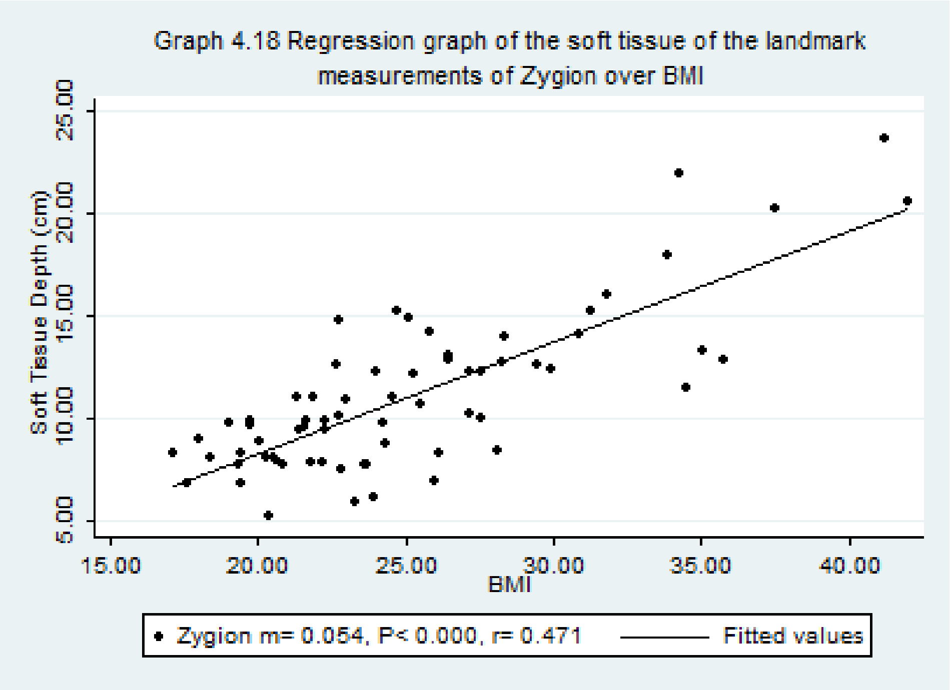
Mot = Maximum Occipital Point, m= gradient

Landmarks	m-value	P-value	r-value	R-squared
Go	0.090	P< 0.000	0.739	0.546
Z	0.054	P< 0.000	0.702	0.493
Gn	0.048	P< 0.000	0.628	0.395
Po	0.031	P< 0.000	0.471	0.221
E	0.021	P< 0.000	0.458	0.210
Mot	0.019	P< 0.000	0.523	0.273
Op	0.017	P< 0.000	0.714	0.509
N	0.016	P< 0.000	0.461	0.213
G	0.016	P< 0.000	0.705	0.497
Sm	0.014	0.026	0.272	0.074
In	0.013	P< 0.000	0.507	0.257

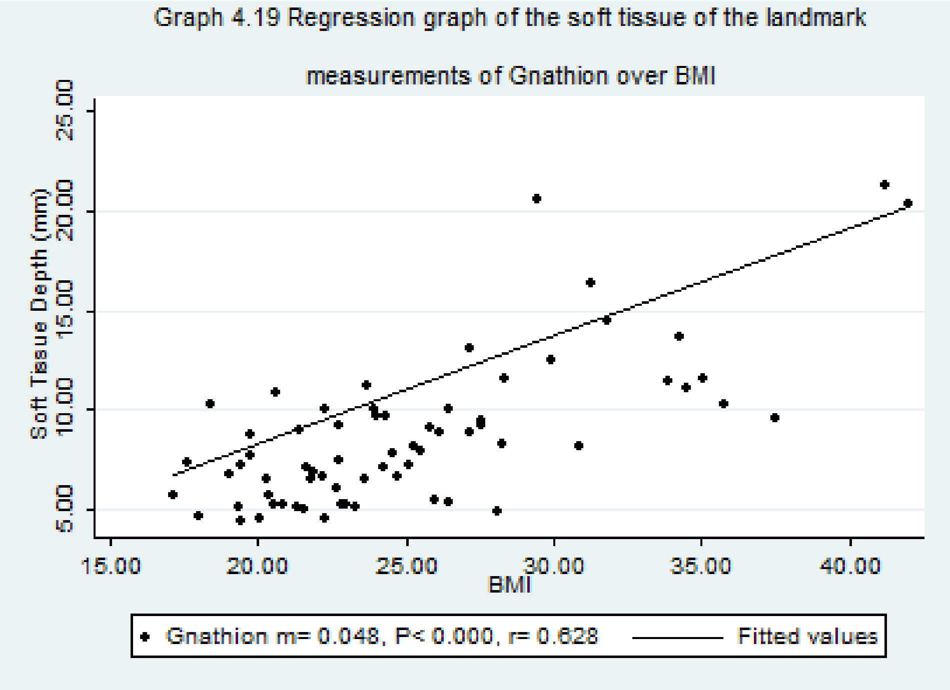
Ml	0.012	0.097	0.205	0.042
V	0.011	0.001	0.394	0.155
Mp	0.011	0.074	0.220	0.048
R	0.009	P< 0.000	0.460	0.212
Pr	0.004	0.318	0.124	0.015
Nt	0.000	0.786	0.034	0.001

Graph 4.17 Regression graph of the soft tissue of the landmark measurements of Gonion over BMI

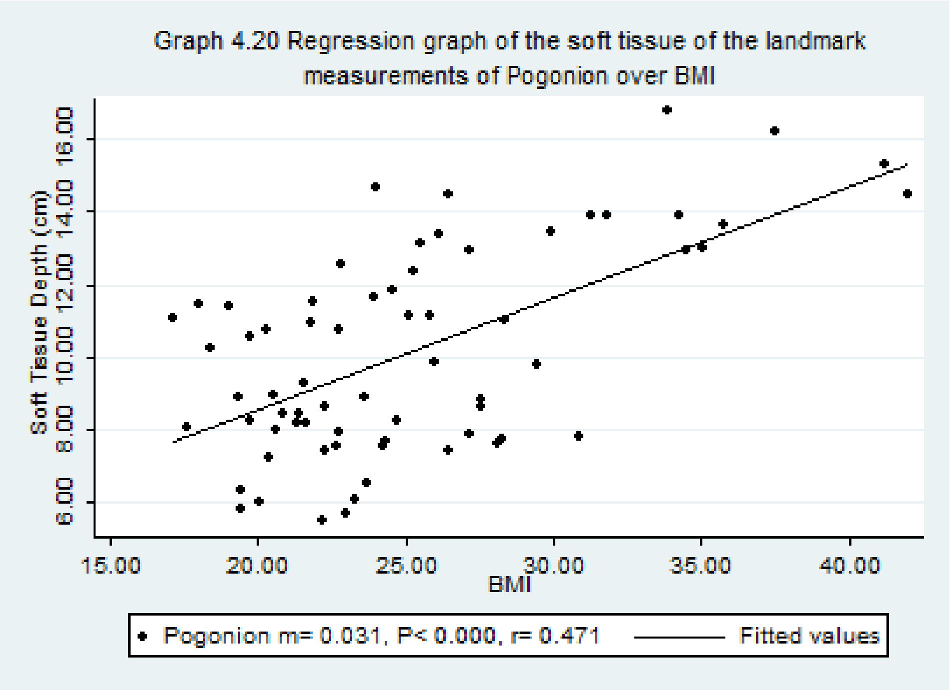




Graph 4.18 Regression graph of the soft tissue of the landmark measurements of Zygion over BMI



Graph 4.19 Regression graph of the soft tissue of the landmark measurements of Gnathion over BMI



Note that the four landmarks, those that undergo the greatest change with changes in body fat percentage or BMI, can be grouped into two areas of the face: Gonion and Zygion on the lateral aspects or widths, and Gnathion and Pogonion on the chin (See Figure 4.1).

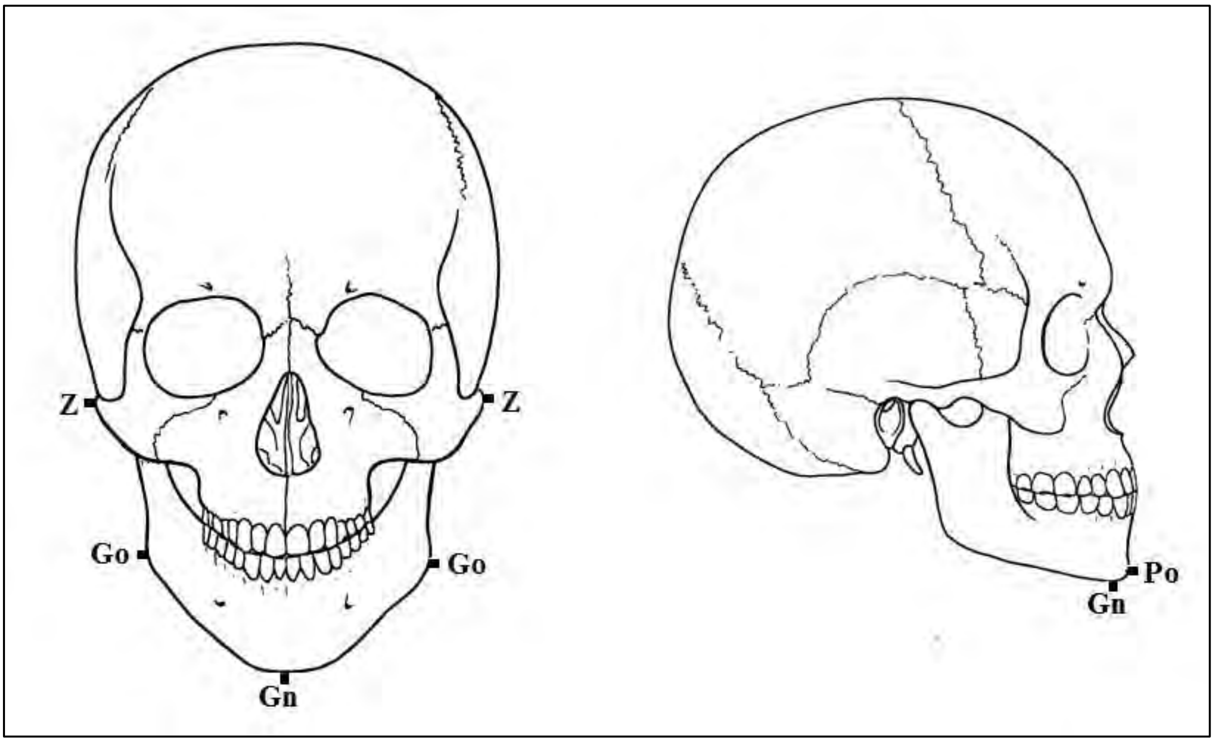


Figure 4.1 Areas of greatest change with change in Body Fat Percentage

4.4.3. REGRESSION ANALYSIS BY SEX

4.4.3.1. DESCRIPTIVE STATISTICS OF SEX

Descriptive statistics were performed for each variable; including the mean, standard deviation, maximum and minimum. Table 4.6 summarizes the results by sex.

The 67 participants of this study, consisted of 17 (25.37%) males and 50 (74.63%) females.

Males and females had similar ranges for age, which was expected with the volunteers being recruited from the student population of the Health Sciences Faculty of the University of Cape Town. Females were of the youngest and oldest ages, 18 and 50 respectively, though both males and females had similar mean ages (23.0 and 23.8, respectively).

Males were taller (with a maximum height of 185.60cm and mean height of 174.1cm) than females (with a minimum height of 148.70cm and mean height of 163.8cm). The weight of males was higher (the mean of 77.7kg, median of 71.6kg larger than the female mean of 67.2kg and median of 64.5kg) with a greater standard deviation (SD= 20.1).

While the BMI mean for females was similar to males (25.1 g/m^2 and 25.4 g/m^2, respectively) the range was greater for females who had both the highest (41.99 kg/m^2) and lowest (17.20kg/m^2) measurements. Females also had the highest body fat percentage (40.7%), with three of the four skinfold measurements being higher than for males, though males had the lowest body fat percentage (7.8%). Looking at the values for the means and medians of body fat percentage shows that females had tended to still have the larger body fat percentage by over 10%.

Comparing the means and medians of the skinfold measurements showed that the skinfold measurements of females remained greater but were actually similar for the subscapular and supra-iliac measurements. Both males and females had the same minimum measurement for the Subscapular skinfold (5.83), though the mean was larger for males (14.6).

Table 4.6 The descriptive statistics of the participant data, divided by sex.

% Fat= Body Fat Percentage, St Dev.= Standard Deviation

Measurements	**Male**						**Female**					
	n	**Mean**	**Median**	**St Dev.**	**Max**	**Min**	**n**	**Mean**	**Median**	**St Dev.**	**Max**	**Min**
Age (years)	17	23.8	23.0	6.0	45	19	50	23.0	22.0	5.5	50	18
Height (cm)	17	174.1	173.0	6.9	185.6	160.2	50	163.8	163.8	7.3	179.6	148.7
Weight (kg)	17	77.7	71.6	20.1	141.8	52.3	50	67.2	64.5	15.5	112.8	44.3
BMI ($kg/m^{2)}$	17	25.4	24.1	5.2	41.2	20.4	50	25.1	23.4	5.7	42.0	17.2
Biceps	17	5.2	4.6	3.7	16.4	2.5	50	10.5	8.6	5.9	30.5	2.6
Triceps	17	13.9	13	7.8	33.5	4.6	50	23.5	22.4	8.6	46.0	6.2
Subscapular	17	14.6	14.5	6.1	32.1	5.8	50	14.9	14.9	6.7	43.2	5.8
Supra-iliac	17	14.7	13.6	7.9	33.9	5.8	50	14.8	14.4	6.2	32.1	2.0
% Fat	17	17.8	17.2	5.9	28.1	7.8	50	29.5	28.7	5.3	40.7	19.9

4.4.3.2. REGRESSION ANALYSIS BY SEX

A total of 17 male and 50 female participants were measured in this study. The gradients were found to be higher for all of the landmarks measurements when separated by the variable of sex, correlated with body fat percentage.

4.4.3.2.1. FEMALES

4.4.3.2.1.1. BODY FAT PERCENTAGE REGRESSION ANALYSIS OF FEMALES

The landmark measurements of the female participants (Summarized in Table 4.7) displayed a similar arrangement to that seen in the above chapters. Eleven of the 17 landmarks were found to be significant, while Gonion, Zygion, Gnathion and Pogonion were, again, the four highest gradients and found to have significant correlation values.

Gonion (Graph 4.21) had the greatest gradient (m= 0.069, r= 0.665), while Zygion (Graph 4.23) had the highest correlation (m= 0.042, r= 0.692).

Inion was the 5th greatest gradient (m= 0.017) that was significantly correlated to body fat percentage, with a moderate positive correlation (r= 0.553). Euryon was the 6th greatest gradient (m= 0.017) that was significantly correlated to body fat percentage, with a weak to moderate positive correlation (r= 0.404). Graph 4.25 and graph 4.26 displays Euryon and Inion, respectively.

Nasion, Maximum Occipital Point, Glabella, Supra-mentale and Ophryon were the other significantly correlated landmarks. Nasion, Glabella and Ophryon had moderately positive correlated , while Maximum Occipital Point and Supra-mentale were weakly correlated.

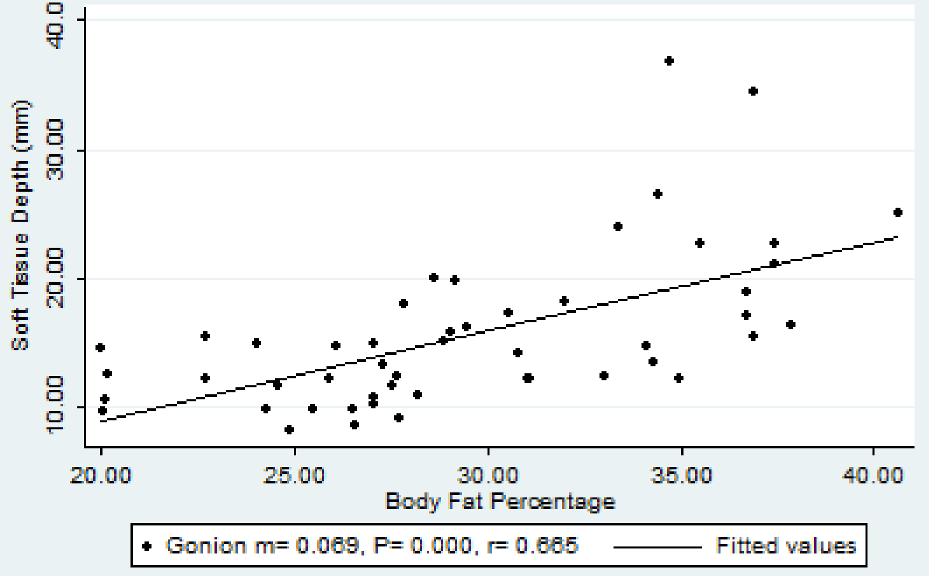
Table 4.7 Regression values of soft tissue measurements of female participants and Body Fat Percentage, ordered by gradient.

Mot= Maximum Occipital Point, m= gradient

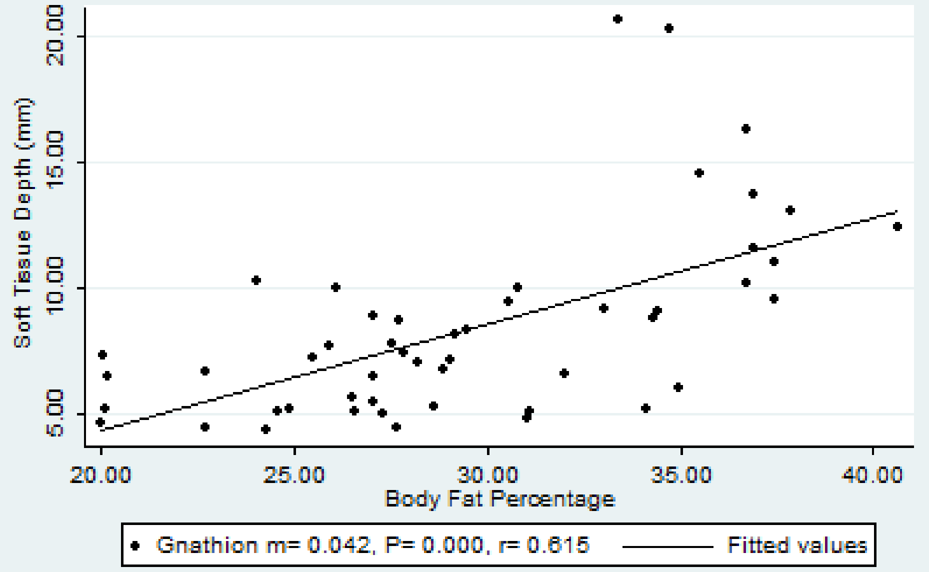
Landmarks	m-value	P-value	r-value	R-squared
Go	0.069	P< 0.000	0.665	0.443
Gn	0.042	P< 0.000	0.615	0.378
Z	0.042	P< 0.000	0.692	0.479
Po	0.026	0.003	0.412	0.17
E	0.017	0.004	0.404	0.163
In	0.017	P< 0.000	0.553	0.306
N	0.014	P< 0.000	0.545	0.297
Mot	0.014	0.006	0.383	0.147
G	0.013	P< 0.000	0.628	0.394
Mp	0.013	0.072	0.257	0.066
Sm	0.012	0.041	0.29	0.084
Op	0.011	P< 0.000	0.53	0.281
Ml	0.009	0.075	0.254	0.065
V	0.006	0.225	0.175	0.031
R	0.005	0.078	0.252	0.063

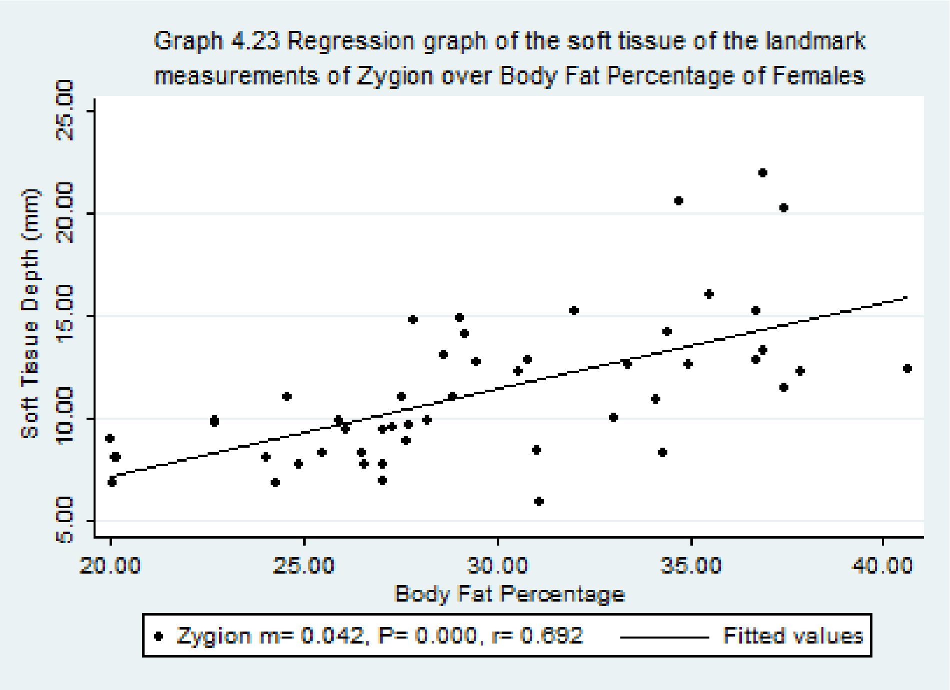
Pr	0.003	0.595	0.077	0.006
Nt	0.001	0.898	0.017	0.00

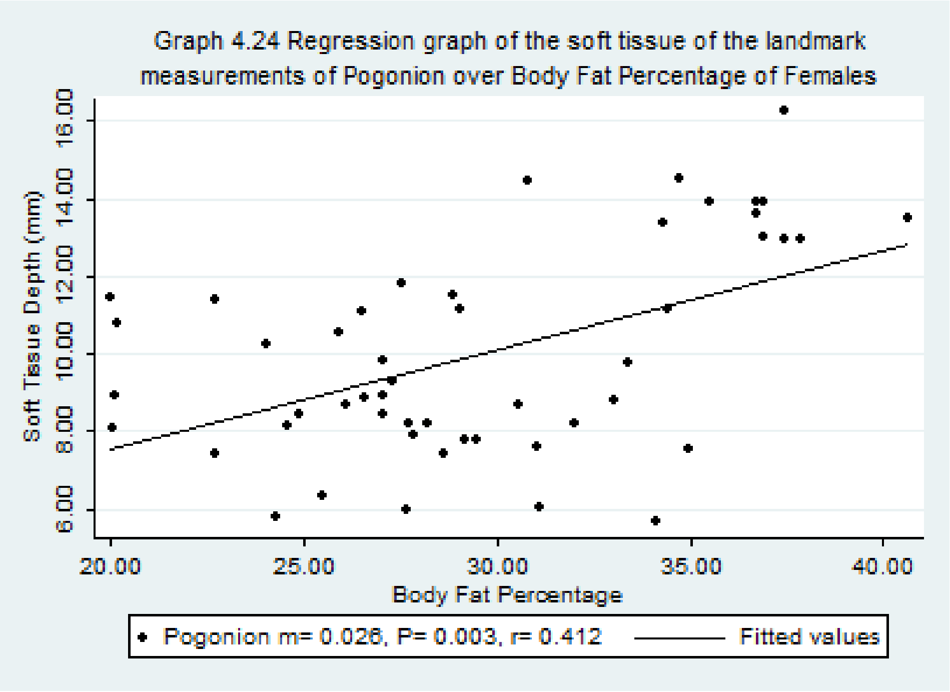
Graph 4.21 Regression graph of the soft tissue of the landmark measurements of Gonion over Body Fat Percentage of Females

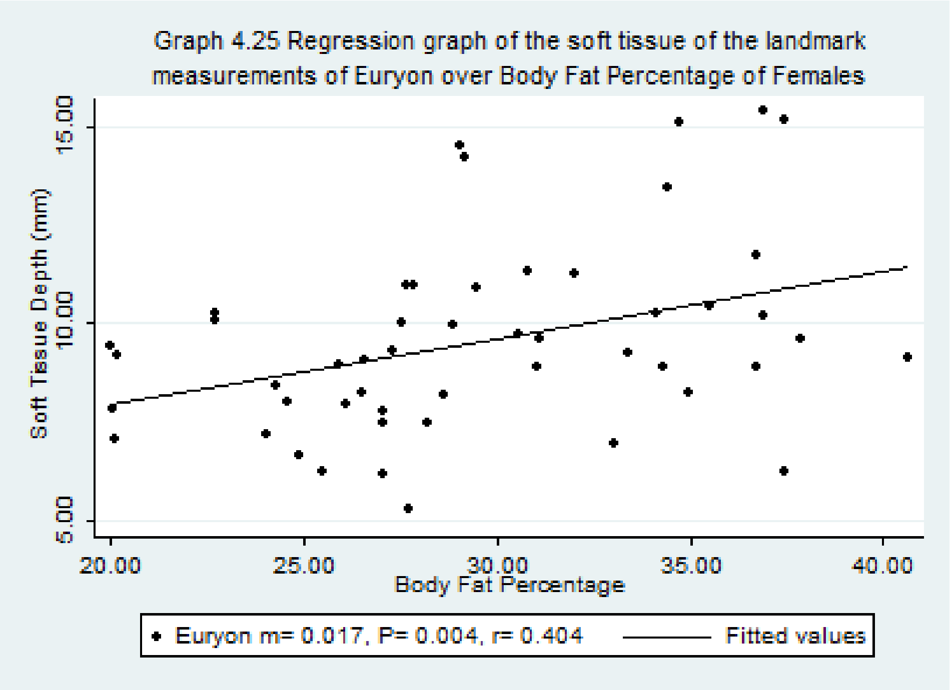


Graph 4.22 Regression graph of the soft tissue of the landmark measurements of Gnathion over Body Fat Percentage of Females

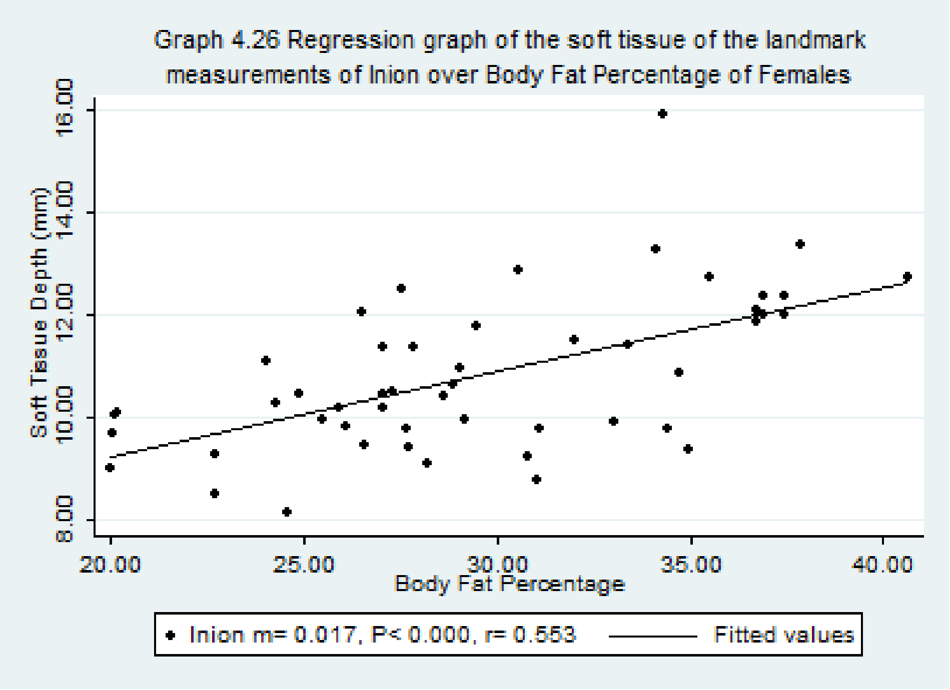



Graph 4.23 Regression graph of the soft tissue of the landmark measurements of Zygion over Body Fat Percentage of Females


Graph 4.24 Regression graph of the soft tissue of the landmark measurements of Pogonion over Body Fat Percentage of Females



Graph 4.25 Regression graph of the soft tissue of the landmark measurements of Euryon over Body Fat Percentage of Females



Graph 4.26 Regression graph of the soft tissue of the landmark measurements of Inion over Body Fat Percentage of Females

There were two outliers for Gonion, three for Zygion, two for Gnathion, one for Inion and one for Euryon. Two of the outliers for Gonion and Zygion, as well as one outlier for Inion and Euryon, were from the same individual as in Chapter 4.2.3.

4.4.3.2.1.2. BMI REGRESSION ANALYSIS OF FEMALES

The landmark measurements of the female participants (Summarized in Table 4.8) displayed a similar arrangement to that seen in the above BMI comparison. Thirteen of the 17 landmarks were found to be significant, while Gonion, Zygion, Gnathion and Pogonion were again the highest four gradients and found to be significant.

Gonion (Graph 4.27) had the highest gradient (m= 0.081) and strongest correlation (r= 0.764). Zygion (Graph 4.28) had the 2nd greatest gradient (m= 0.47) and was strong correlated (r= 0.712) to BMI. Gnathion (Graph 4.29) and Pogonion (Graph 4.30) were the third and fourth highest gradients (m= 0.045 and m= 0.028, repsectively), with weak to moderate correlations (r= 0.619 and r= 0.435, respectively).

Compared to the correlations of body fat percentage (Chapter 4.2.2.1.2), Zygion and Gnathion switched positions, though their gradients remained similar.

Euryon, Maximum Occipital Point. Ophryon, Supra-mentale, Glabella, Vertex, Inion, Nasion and Rhinion were the other significant landmarks. Of which, Ophryon and Glabella had strong correlations (r= 0.720 and r= 0.741, respectively) with BMI.

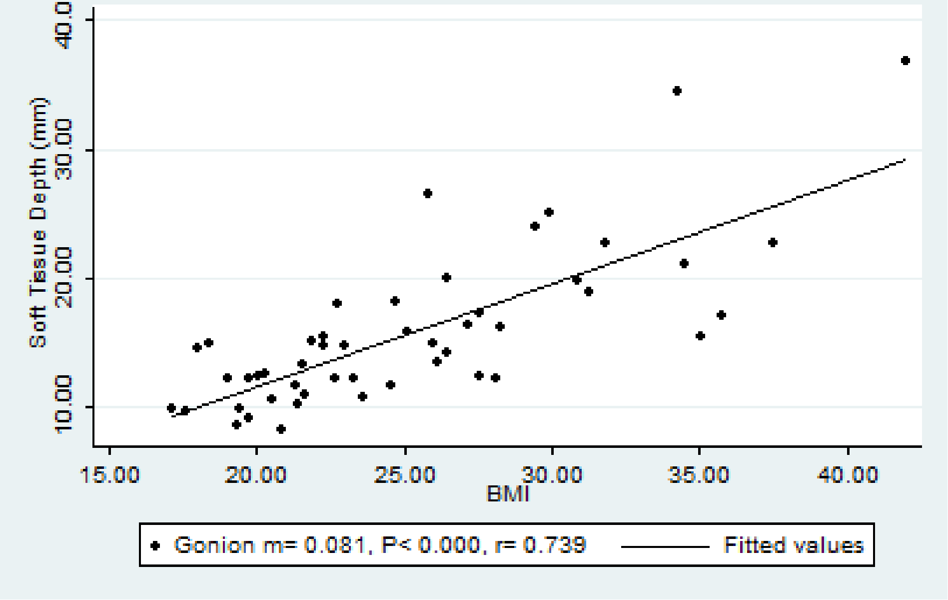
The correlation of the measurements was significant for all landmarks but Mid-philtrum, Mid-lip, Prosthion and Nasal tip.

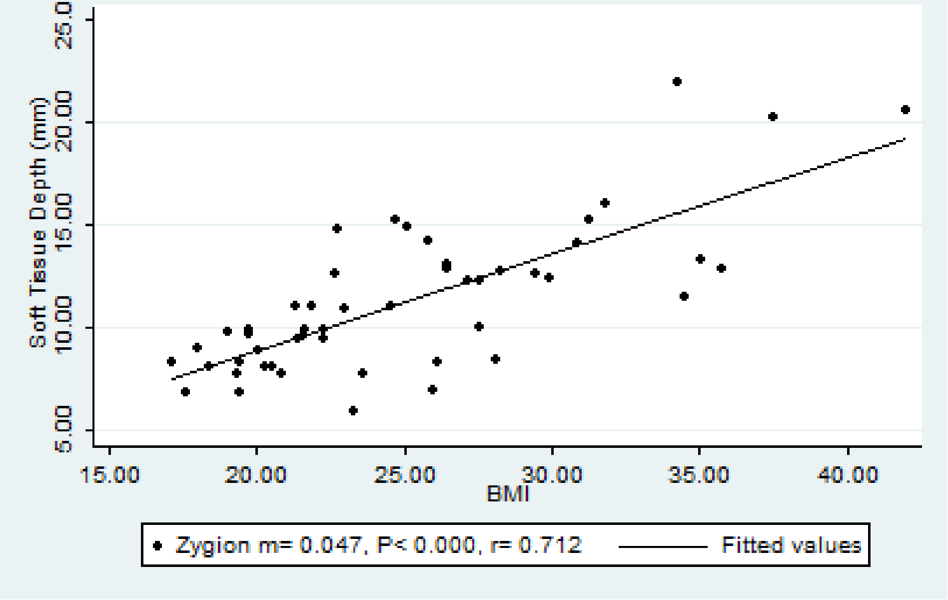
Table 4.8 Regression values of soft tissue measurements of female participants and BMI (kg/m^2), ordered by gradient.

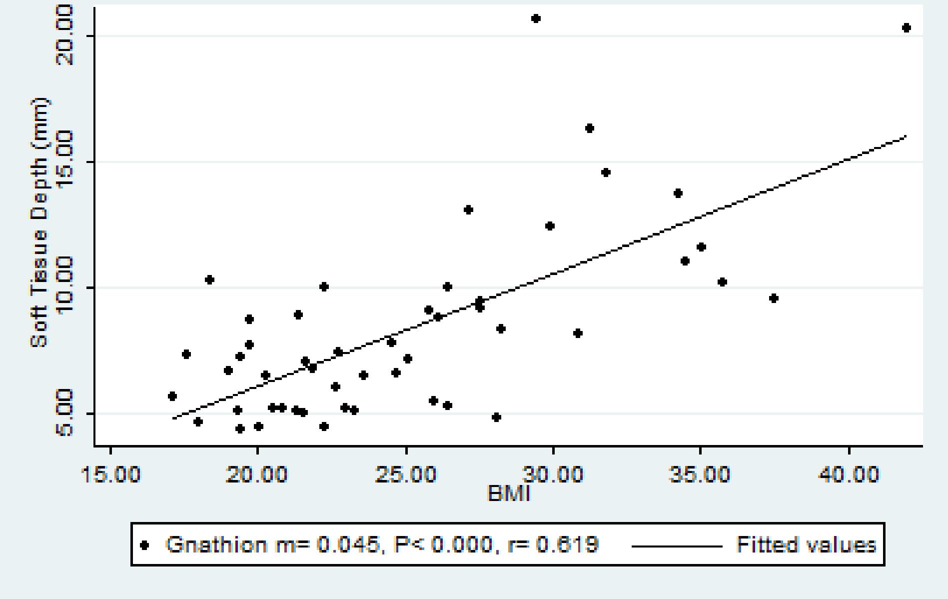
Mot= Maximum Occipital Point, m= gradient

Landmarks	m-value	P-value	r-value	R-squared
Go	0.081	P< 0.000	0.764	0.584
Z	0.047	P< 0.000	0.712	0.506
Gn	0.045	P< 0.000	0.619	0.383
Po	0.028	0.002	0.435	0.189
E	0.022	0.002	0.437	0.191
Mot	0.018	P< 0.000	0.513	0.263
Op	0.016	P< 0.000	0.720	0.519
Sm	0.016	0.021	0.325	0.106
G	0.015	P< 0.000	0.741	0.549
V	0.013	0.007	0.379	0.144
In	0.012	P< 0.000	0.500	0.250
N	0.011	0.001	0.465	0.216
Mp	0.010	0.103	0.234	0.055
Ml	0.010	0.187	0.190	0.036
R	0.008	0.002	0.431	0.185

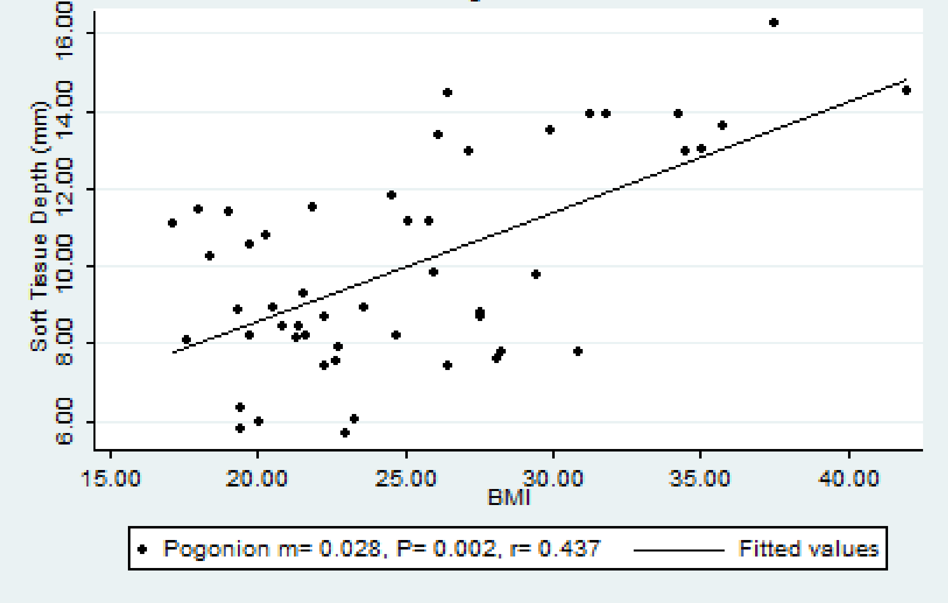
Pr	0.000	0.709	0.054	0.003
Nt	0.000	0.838	0.030	0.001


Graph 4.27 Regression graph of the soft tissue of the landmark measurements of Gonion over BMI of Females

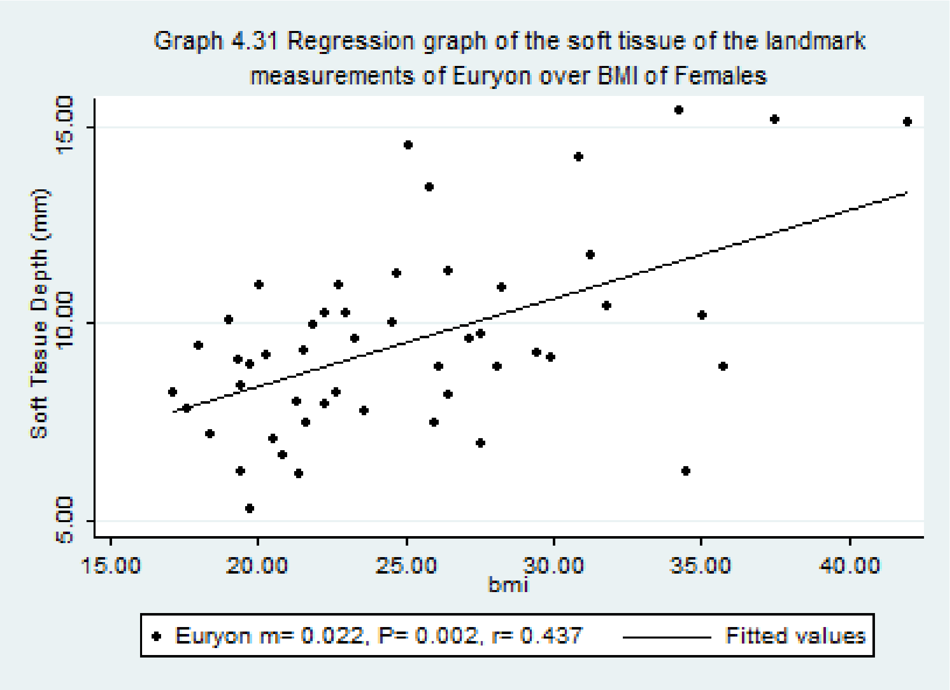

Graph 4.28 Regression graph of the soft tissue of the landmark measurements of Zygion over BMI of Females



Graph 4.29 Regression graph of the soft tissue of the landmark measurements of Gnathion over BMI of Females



Graph 4.30 Regression graph of the soft tissue landmark measurements of Pogonion over BMI of Females



Graph 4.31 Regression graph of the soft tissue of the landmark measurements of Euryon over BMI of Females

4.4.3.2.2. MALES

4.4.3.2.2.1. BODY FAT PERCENTAGE REGRESSION ANALYSIS OF MALES

The landmark measurements of the male participants (Summarized in Table 4.9) again displayed a similar arrangement to that seen in the above chapters. Nine of the 17 landmarks were found to be significant, while Gonion, Zygion, Gnathion and Pogonion were again the four highest gradients and found to be significant.

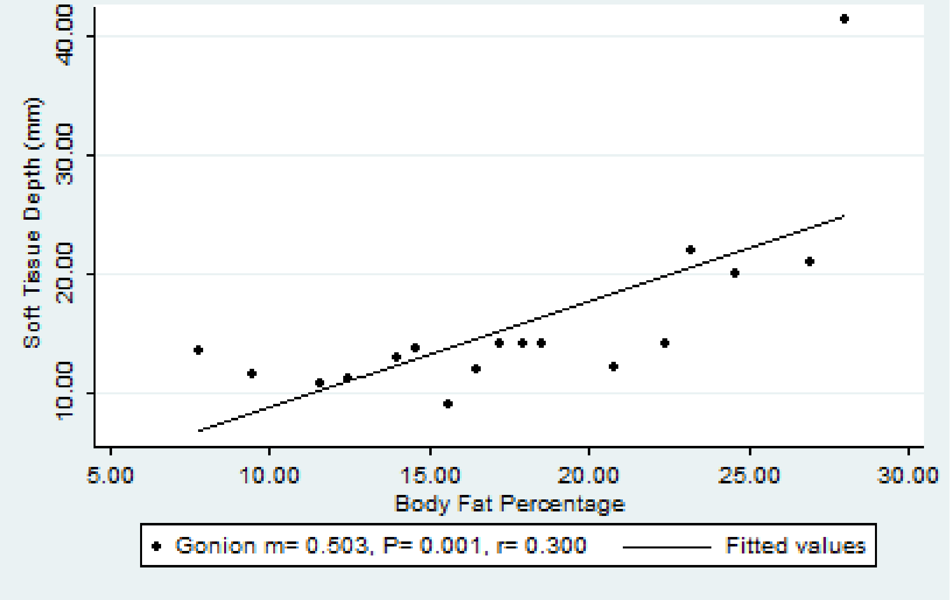
Zygion (Graph 4.34) replaced Gonion (Graph 4.32) as the landmark having the highest gradient (m= 0.589) and the highest and strongest positive correlation (r= 0.824). This indicates that while Zygion did not increase as greatly as Gonion or Gnathion, the change had a greater predictability.

The result for Gnathion (Graph 4.33) show that it had the second greatest gradient, but the r-value indicated it had the lowest correlation of the top four landmarks correlations with body fat percentage.

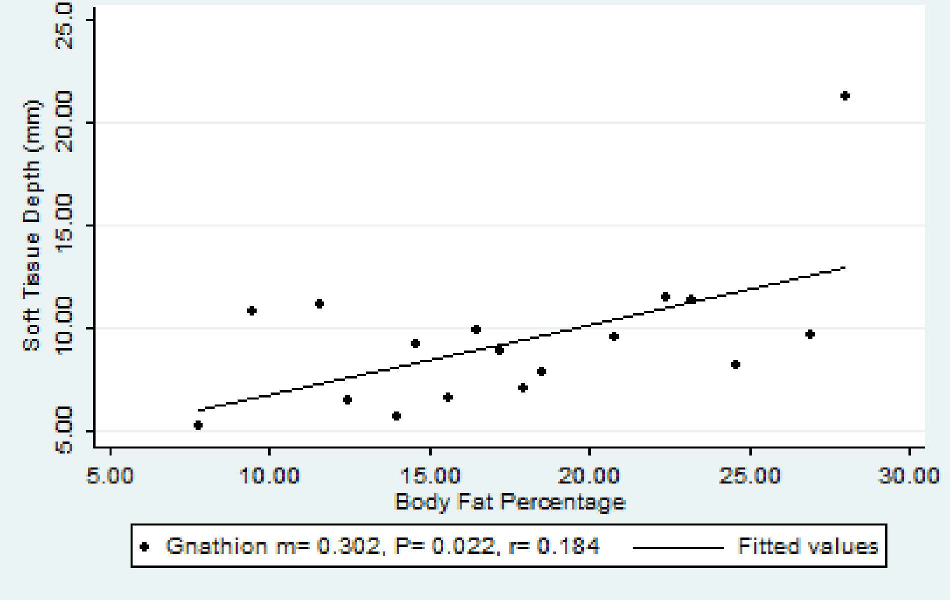
Table 4.9 Regression values of soft tissue measurements of male participants and Body Fat Percentage, ordered by gradient. Mot= Maximum Occipital Point, m= gradient				
Landmarks	**m-value**	**P-value**	**r-value**	**R-squared**
Go	0.503	0.001	0.300	0.090
Gn	0.302	0.022	0.184	0.034
Z	0.059	P< 0.000	0.824	0.678
Po	0.031	0.027	0.534	0.285
Mot	0.025	P< 0.000	0.765	0.585
E	0.023	0.010	0.605	0.367
N	0.013	0.451	0.196	0.038
In	0.012	0.038	0.508	0.258
R	0.011	0.005	0.653	0.426
V	0.009	0.047	0.488	0.238
Op	0.008	0.309	0.232	0.054
Ml	0.006	0.451	0.196	0.038
G	0.005	0.445	0.199	0.039
Sm	0.005	0.586	0.142	0.020
Mp	0.003	0.794	0.069	0.005
Pr	-0.005	0.660	-0.115	0.013

Nt	-0.024	0.439	-0.201	0.040

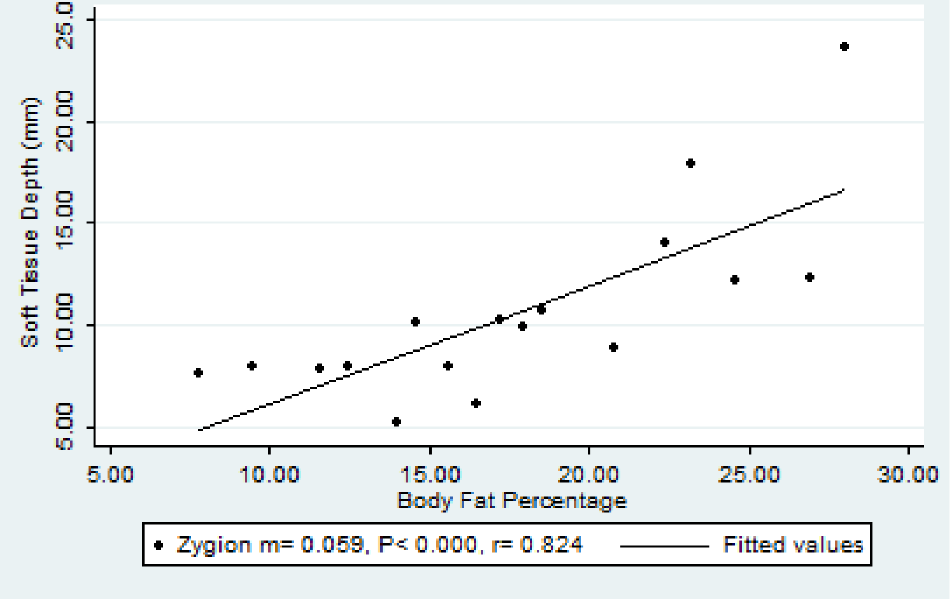
Graph 4.32 Regression graph of the soft tissue of the landmark measurements of Gonion over Body Fat Percentage of Males



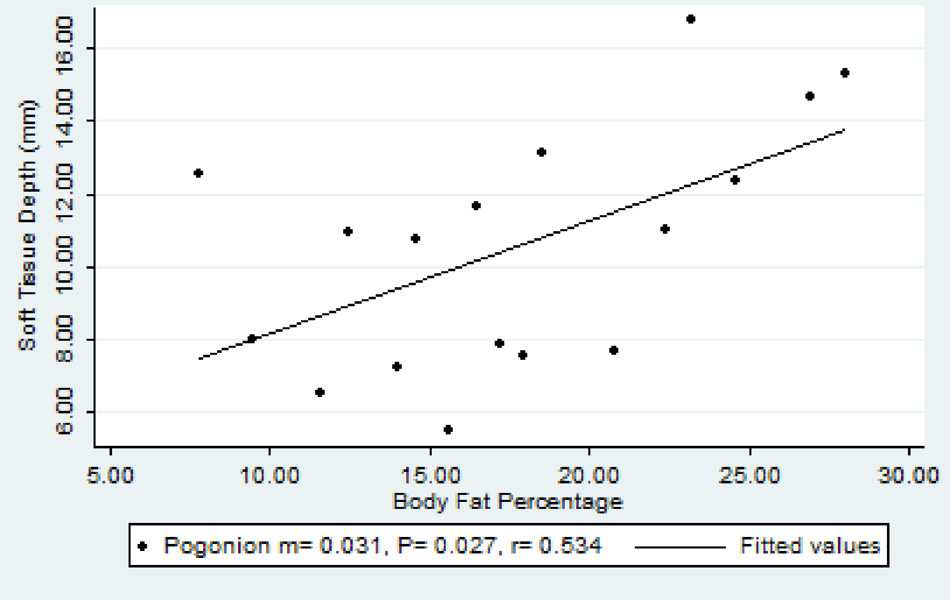
Graph 4.33 Regression graph of the soft tissue of the landmark measurements of Gnathion over Body Fat Percentage of Males



Graph 4.34 Regression graph of the soft tissue of the landmark measurements of Zygionover Body Fat Percentage of Males



Graph 4.35 Regression graph of the soft tissue of the landmark measurements of Pogonion over Body Fat Percentage of Males



Similarly to females, Maximum Occipital Point, Euryon and Inion were significantly correlated.

Maximum Occipital Point was the 5th highest gradient (m= 0.025) for males, while it was the eighth with females (m= 0.383). It had a strong positive correlation (r= 0.765) with body fat percentage for males, unlike the weak positive correlation (r= 0.383) for females.

Euryon was the sixth highest gradient (m= 0.023) for males like it was for females (m= 0.017), with a moderate positive correlation (r= 0.605).

Inion was the eighth highest gradient (m= 0.012) for males, lower than for females where it was the fifth highest (m= 0.017). It had a moderate positive correlation (r= 0.508), similar to females (r= 0.553).

Rhinion and Vertex were the other significant landmarks with weak to moderate positive correlations (r= 0.653 and r= 0.488, respectively).

There was one outlier for Gonion, one for Gnathion, one for Zygion, and two for Pogonion. The ourlier of Gonion, Gnathion and Zygion were from the same participant and one of the outliers seen in Chapter 4.2.2.

4.4.3.2.2.2. BMI REGRESSION ANALYSIS OF MALES

The landmark measurements of the male participants (Summarized in Table 4.10) showed that ten of the 17 landmarks were found to be significant. Gonion, Zygion, Gnathion and Pogonion were again the highest gradients and found to be significant.

Gonion had the highest gradient (m= 0.127) and second strongest correlation (r= 0.768). Zygion had the 2nd highest gradient (m= 0.084) and strongest correlation (r= 0.804). Gnathion had the 3rd highest gradient (m= 0.059) and moderately correlated (r= 0.547).

The landmarks were significant for all landmarks but Nasion, Mid-lip, Prosthion, Mid-philtrum, Supra-mentale, Vertex and Nasal tip.

Comparing the regression values of the females and males with BMI; Supra-mentale, Vertex and Nasion were significant in females but not males. The strongest correlations (r> 0.7) in females were Gonion, Zygion, Ophryon and Glabella, while only Gonion and Zygion were strongly correlated in males.

Table 4.10 Regression values of soft tissue measurements of male participants and BMI (kg/m^2), ordered by gradient.

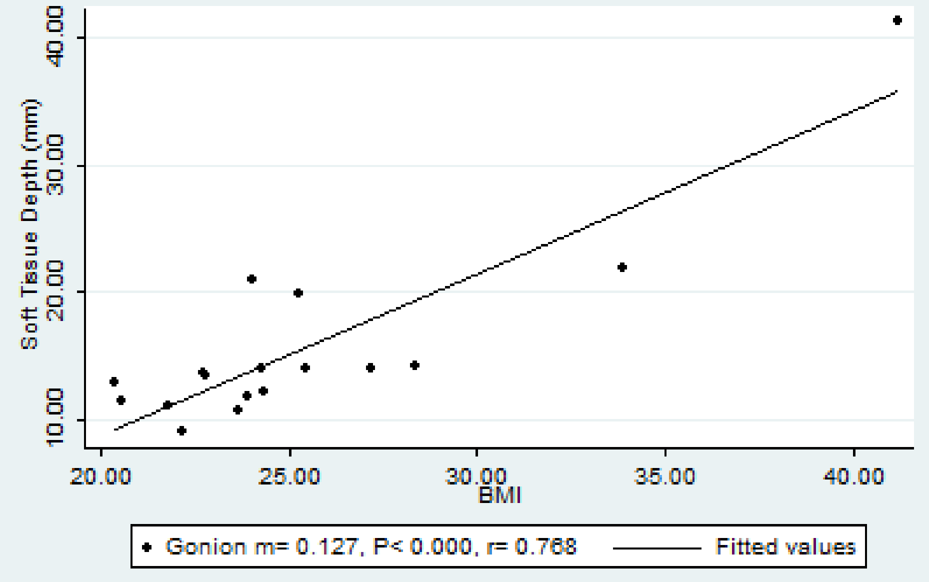
Mot= Maximum Occipital Point, m= gradient

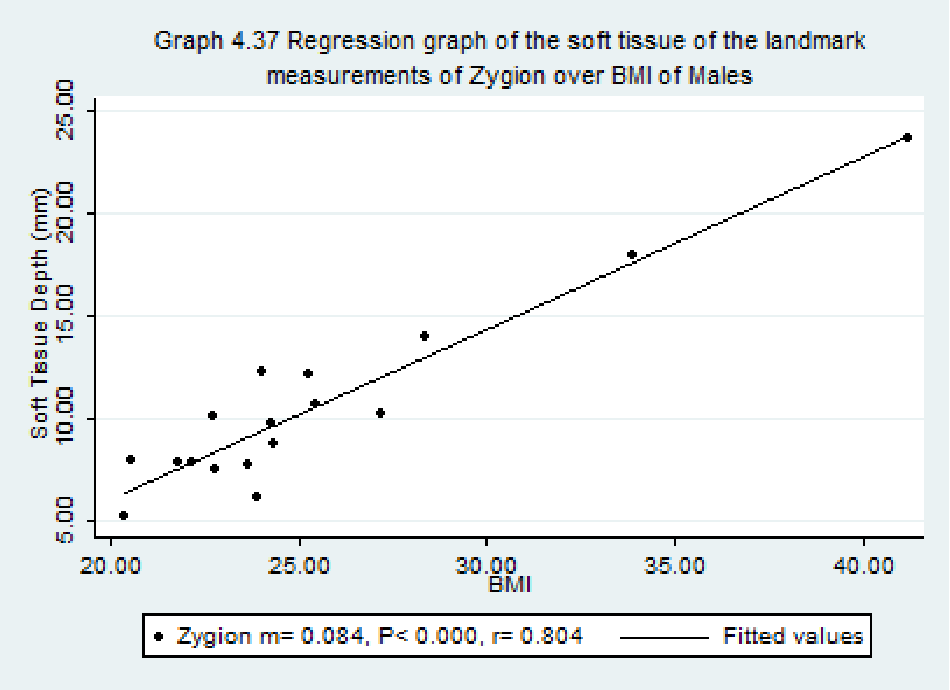
Landmarks	m-value	P-value	r-value	R-squared
Go	0.127	P< 0.000	0.768	0.589
Z	0.084	P< 0.000	0.804	0.646
Gn	0.059	0.023	0.547	0.299
Po	0.040	0.022	0.552	0.304
N	0.035	0.092	0.422	0.178
Mot	0.022	0.008	0.618	0.381
Op	0.018	0.037	0.510	0.260
Ml	0.018	0.395	0.221	0.049
G	0.018	0.032	0.522	0.273
In	0.017	0.030	0.526	0.277
E	0.016	0.031	0.052	0.003
Pr	0.015	0.881	0.039	0.002
R	0.012	0.030	0.525	0.276
Mp	0.010	0.993	-0.003	0.000
Sm	0.008	0.687	0.105	0.011

V	0.006	0.056	0.471	0.222
Nt	0.000	0.896	0.034	0.001

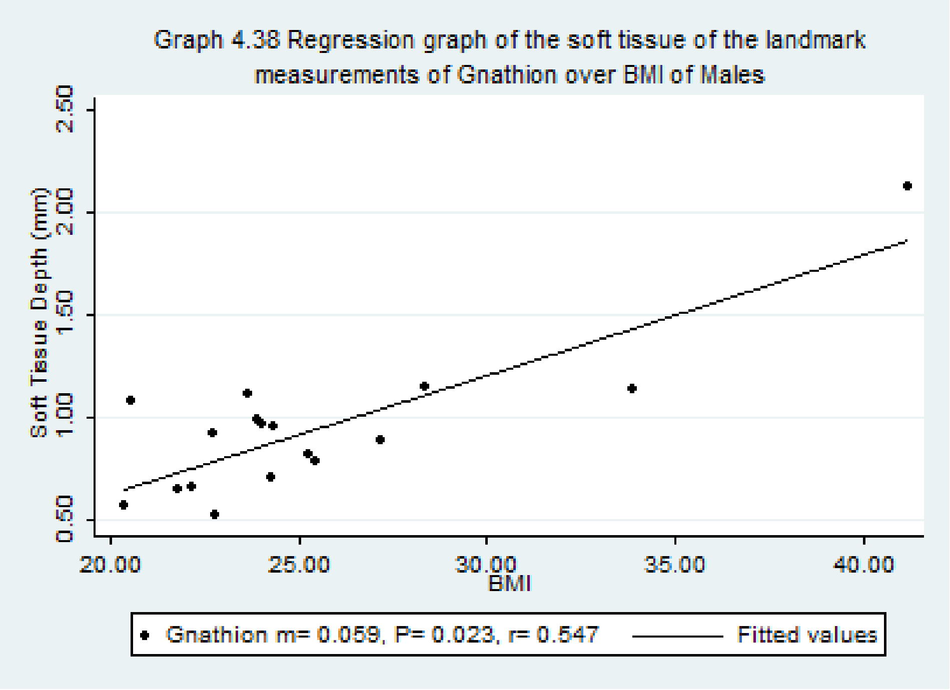
Like in females, Gonion and Zygion switched positions when correlated over BMI instead of body fat percentage. And while their gradients decreased with BMI, the correlation increased, indicating that, for males, Gonion and Zygion increased less with increased BMI but that increase was more predictable.

Graph 4.36 Regression graph of the soft tissue of the landmark measurements of Gonion over BMI of Males

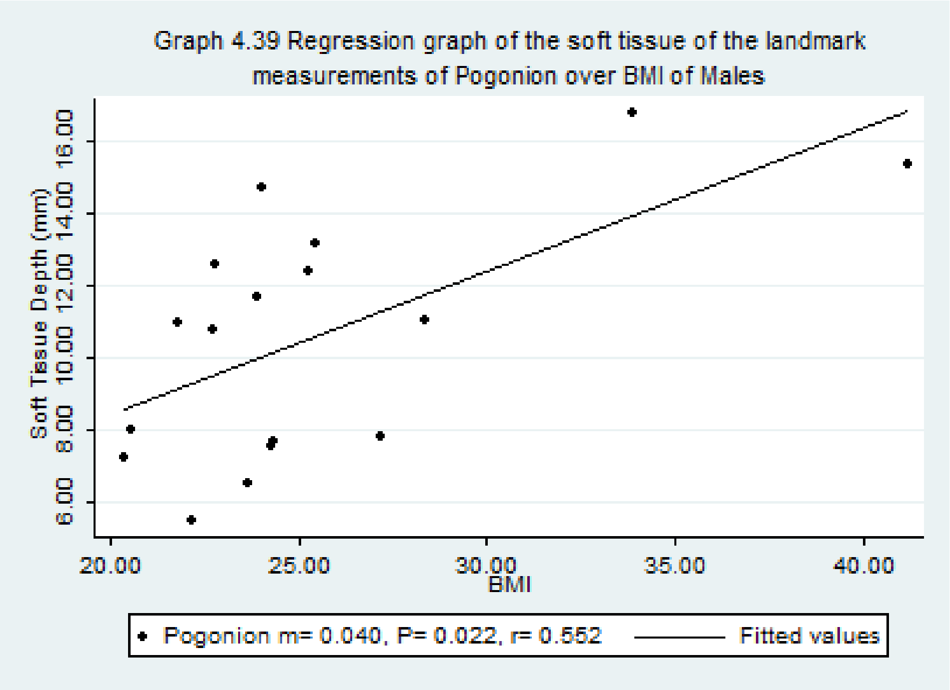




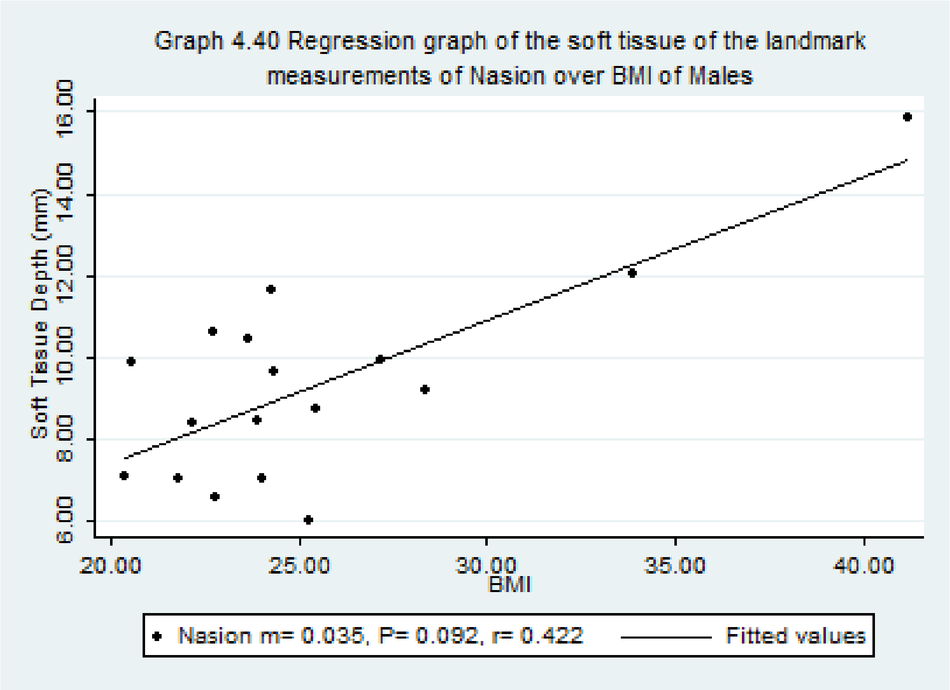
Graph 4.37 Regression graph of the soft tissue of the landmark measurements of Zygion over BMI of Males



Graph 4.38 Regression graph of the soft tissue of the landmark measurements of Gnathion over BMI of Males



Graph 4.39 Regression graph of the soft tissue of the landmark measurements of Pogonion over BMI of Males



Graph 4.40 Regression graph of the soft tissue of the landmark measurements of Nasion over BMI of Males

4.4.3.3. SEX COMPARISONS

Both sexes, irrespective of body fat percentage or BMI, showed that changes to fatness affected Gonion the most. The increase was less with body fat percentage but correlation was high for both measures of fatness.

Body fat percentage had a similar impact as BMI for females, as the correlation values were similar. Yet, in males, BMI had the greater impact of the two measures of fatness, as the correlation values were higher. This indicates that soft tissue thicknesses are more greatly impacted by the total body mass (fat, muscle, bone) than females.

While both sexes showed that fatness had significant influence around the lower face and jaw, females were also affected by changes in fatness around the upper nose and upper face. Males were also affected by changes in fatness around the upper nose and lower lip.

However, it must be noted that the smaller sample size of males will have likely reduced the significance of the results. The smaller sample size may mean that significance is seen where none exists.

4.4.4. REGRESSION ANALYSIS BY ANCESTRY GROUP

4.4.4.1. DESCRIPTIVE STATISTICS OF ANCESTRY GROUP

In this study, participants were requested to self-identify their population group as given by Statistics South Africa (Census 2011). Of the 67 participants two Indian/Asian, 29 White, 22 Black African, 11 Coloured, one Other and two non-identified individuals were measured. Due to the small sample size, the Black African and Coloured measurements were combined for the population group analysis (Refer to Table 4.11 for distribution). The Indian/Asian, Other and non-identified individuals measurements were not analysed in this section.

Table 4.11. The descriptive statistics of the participant data, divided by ancestry.
% Fat= Body Fat Percentage, St Dev.= Standard Deviation

Measurements	Black African and Coloured						White					
	n	Mean	Median	St Dev.	Max	Min	n	Mean	Median	St Dev.	Max	Min
Age (years)	33	22.8	21.0	6.0	45	18	29	24.0	23.0	5.5	50	19
Height (cm)	33	166.3	166.6	8.6	184.3	148.7	29	167.2	165.3	8.7	185.6	149.5
Weight (kg)	33	69.4	68.2	16.5	112.8	44.3	29	69.8	66.9	18.1	141.8	49.6
BMI (kg/m$^{2)}$	33	25.0	24.3	5.0	37.5	17.6	29	25.0	23.6	5.8	41.2	17.2
Biceps	33	7.1	5.5	4.5	20.0	2.5	29	11.2	9.9	6.8	30.5	2.5
Triceps	33	20.4	19.6	9.7	46.0	4.6	29	21.2	18.8	9.3	45.5	5.1
Subscapular	33	14.5	14.2	5.6	30.2	5.8	29	15.4	11.8	7.9	43.2	7.9
Supra-iliac	33	15.1	14.5	6.8	32.1	5.9	29	14.1	13.7	6.7	33.9	2.0
% Fat	33	24.9	24.6	7.8	37.8	7.8	29	27.8	27.7	7.4	40.7	9.5

The ages, heights, weights and BMI measurements of the different ancestry groups were similar. There was a big difference between the bicep measurements, with the White ancestry group having the greater measurements (maximum of 30.5), reinforced by the median measurements (5.5 for Black Africans and Coloureds and 9.9 for Whites). Both possessed the same minimum value of 2.5 for the biceps measurement.

Even though the White ancestry group had the greatest subscapular and supra-iliac measurements (43.2 and 33.9, respectively), the Black Africans and Coloureds had greater median values for those measurements (14.2 and 14.5, respectively). Body fat percentage was larger for Whites, though not a by a large amount. The ancestry groups had the same mean value for BMI (25.0kg/m^2), though Black Africans and Coloureds had the greater median value (24.3).

4.4.4.2. REGRESSION ANALYSIS BY ANCESTRY GROUP

4.4.4.2.1. BLACK AFRICAN AND COLOUREDS

4.4.4.2.1.1. BODY FAT PERCENTAGE REGRESSION ANALYSIS OF BLACK AFRICAN AND COLOUREDS

The landmark measurements of the Black African and Coloured participants (Summarized in Table 4.12) results showed six of the 17 landmarks were significantly correlated and, while, Gonion (Graph 4.41), Zygion (Graph 4.42) and Gnathion (Graph 4.43) had the highest three gradients, only Gonion and Zygion had significant correlation values. The correlation for Gnathion and Pogonion (Graph 4.46) were not significant.

Maximum Occipital Point (Graph 4.44, m= 0.014) and Euryon (Graph 4.45, m= 0.012) were the fourth and fifth highest gradients and were found to be significant. Pogonion (m= 0.011) was the sixth place highest gradient but was not significant (P= 0.122).

Zygion had the highest correlation (r= 0.655), then Gonion (r= 0.693), with similar gradients.

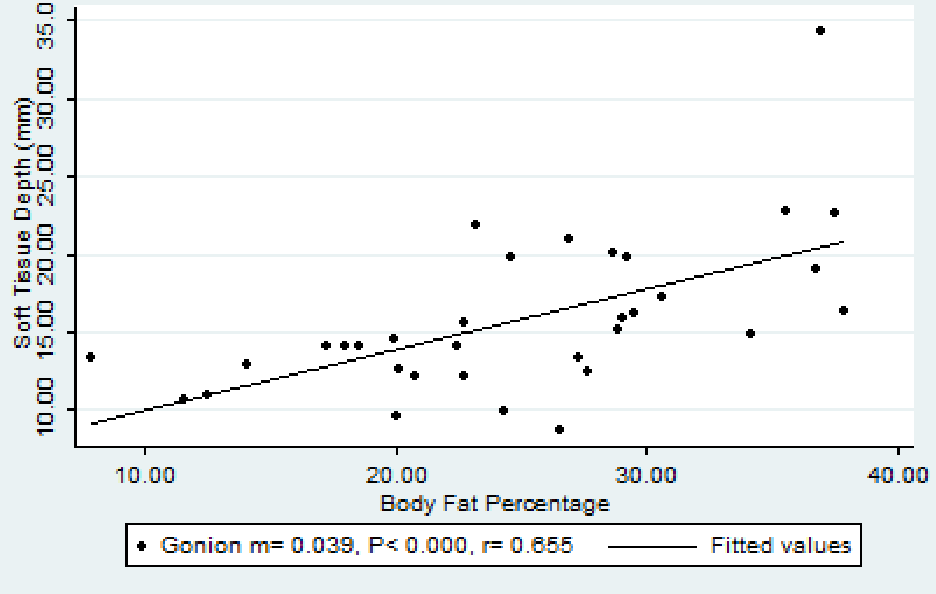
Prosthion had a negative gradient (m= -0.009) and a moderate negative correlation (r= -0.411).

There was one outlier for Gonion, three for Zygion, two for Gnathion, two for Maximum Occipital Point, one for Euryon and one for Prosthion.

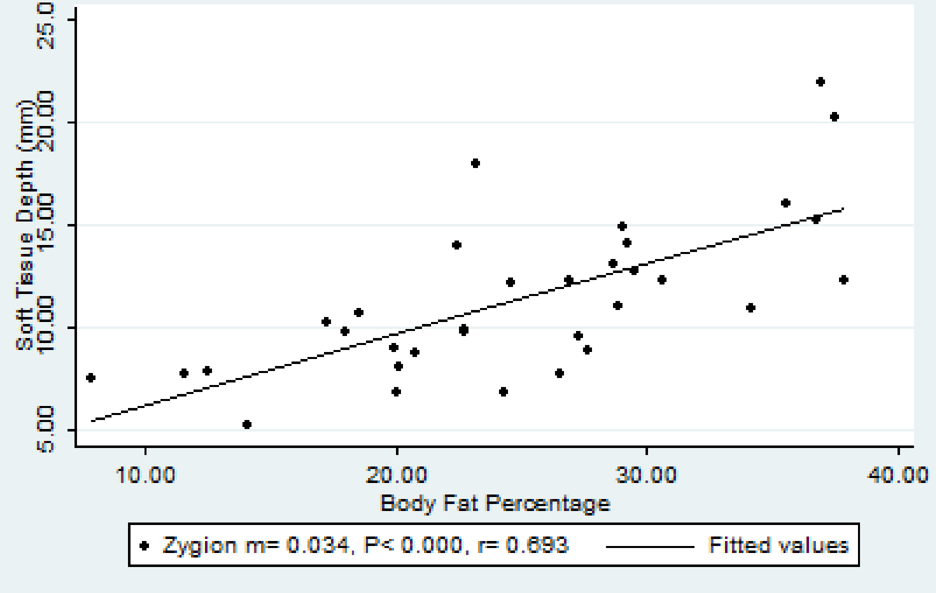
Table 4.12 Regression values of soft tissue measurements of Black African and Coloured participants and Body Fat Percentage, ordered by gradient. **Mot= Maximum Occipital Point, m= gradient**				
Landmarks	**m-value**	**P-value**	**r-value**	**R-squared**
Go	0.039	P< 0.000	0.655	0.429
Z	0.034	P< 0.000	0.693	0.480
Gn	0.017	0.063	0.328	0.107
Mot	0.014	P< 0.000	0.609	0.371
E	0.012	0.010	0.445	0.198
Po	0.011	0.122	0.275	0.076
V	0.007	0.010	0.441	0.194
In	0.006	0.058	0.333	0.111
Op	0.003	0.152	0.255	0.065
R	0.003	0.098	0.293	0.086
G	0.003	0.305	0.184	0.034
Sm	-0.001	0.884	0.026	0.001
N	-0.002	0.669	0.077	0.006
Ml	-0.003	0.213	0.118	0.014
Mp	-0.006	0.508	0.120	0.014
Pr	-0.009	0.018	-0.411	0.169

Nt	-0.015	0.055	0.337	0.114

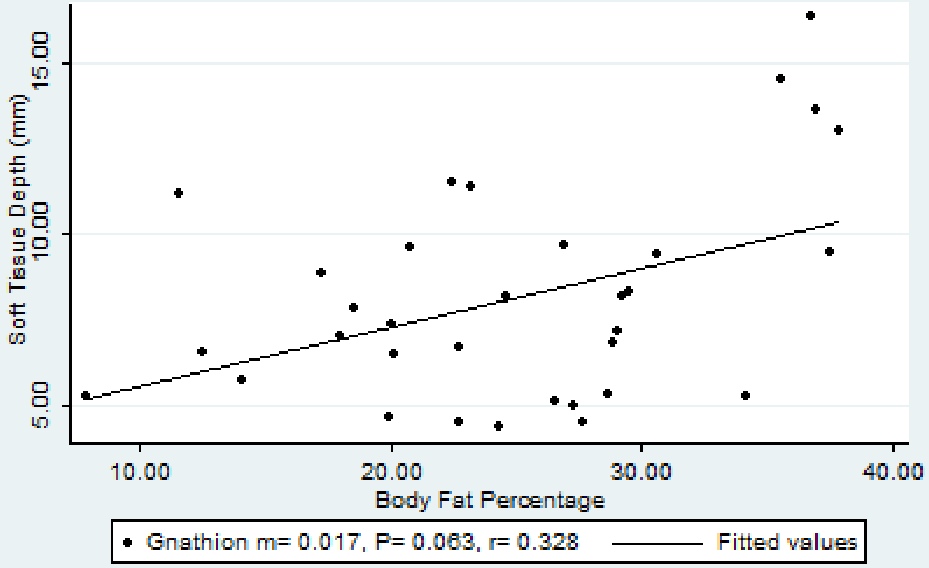
Graph 4.41 Regression graph of the soft tissue of the landmark measurements of Gonion over Body Fat Percentage of Black African and Coloureds



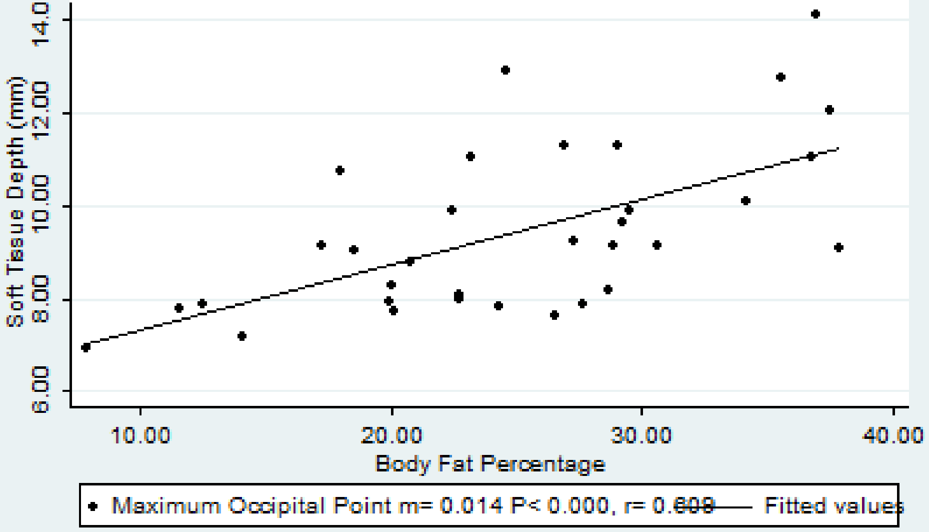
Graph 4.42 Regression graph of the soft tissue of the landmark measurements of Zygion over Body Fat Percentage of Black African and Coloureds

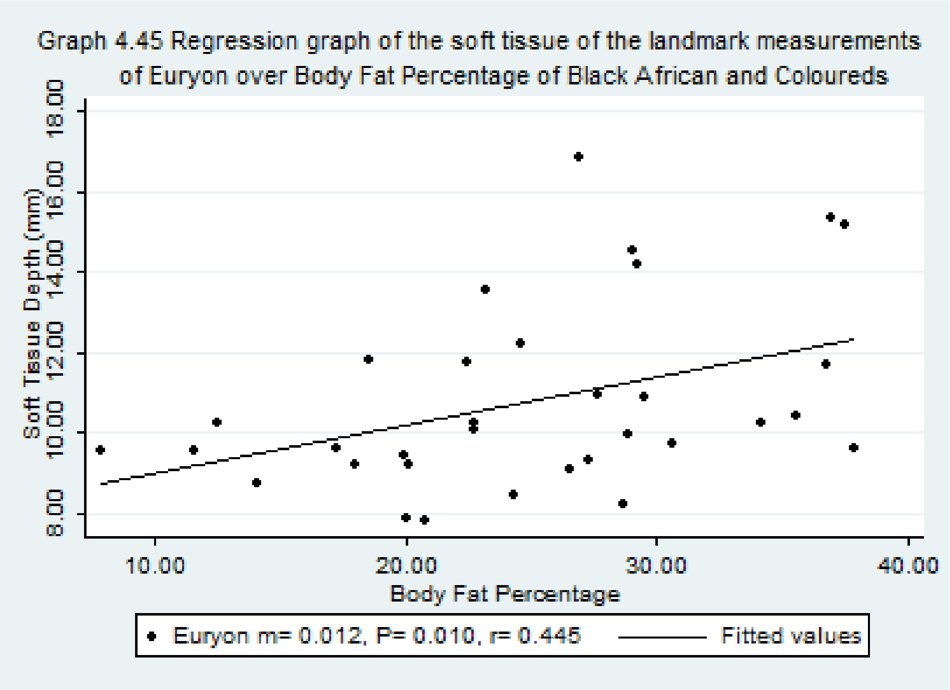


Graph 4.43 Regression graph of the soft tissue of the landmark measurements of Gnathion over Body Fat Percentage of Black African and Coloureds

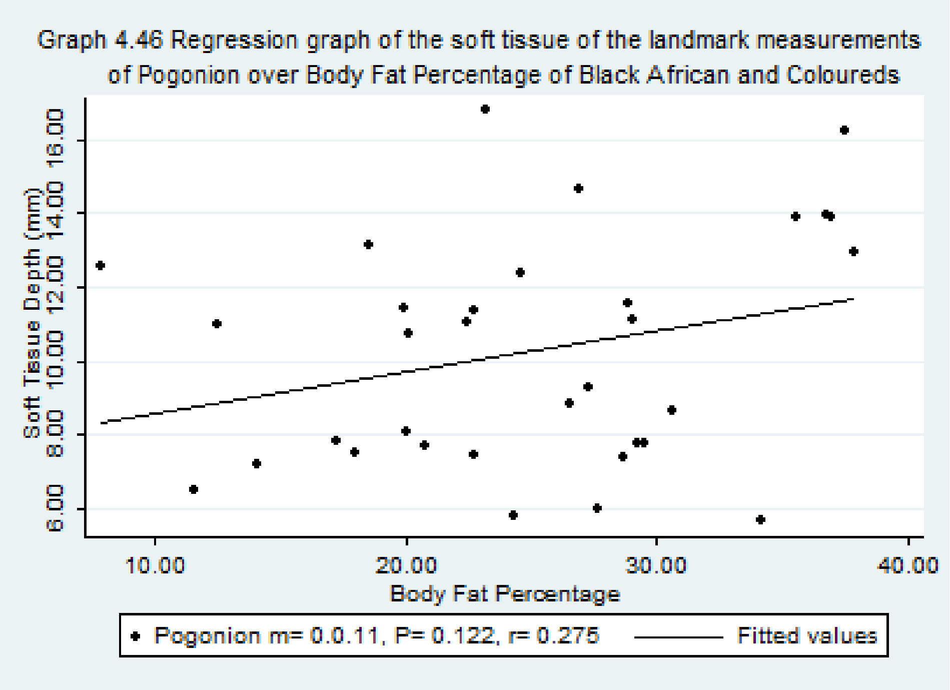


Graph 4.44 Regression graph of the soft tissue of the landmark measurements of Maximum Occipital Point over Body Fat Percentage of Black African and Coloureds





Graph 4.45 Regression graph of the soft tissue of the landmark measurements of Euryon over Body Fat Percentage of Black African and Coloureds



Graph 4.46 Regression graph of the soft tissue of the landmark measurements of Pogonion over Body Fat Percentage of Black African and Coloureds

4.4.4.2.1.2. BMI REGRESSION ANALYSIS OF BLACK AFRICAN AND COLOUREDS

Table 4.13 summarized the results of the regression analysis of Black African and Coloured participants with BMI. Twelve of the 17 landmarks were found to be significant, while Gonion, Zygion, Gnathion and Pogonion were again the highest gradients. Pogonion had changed position compared to the body fat percentage analysis.

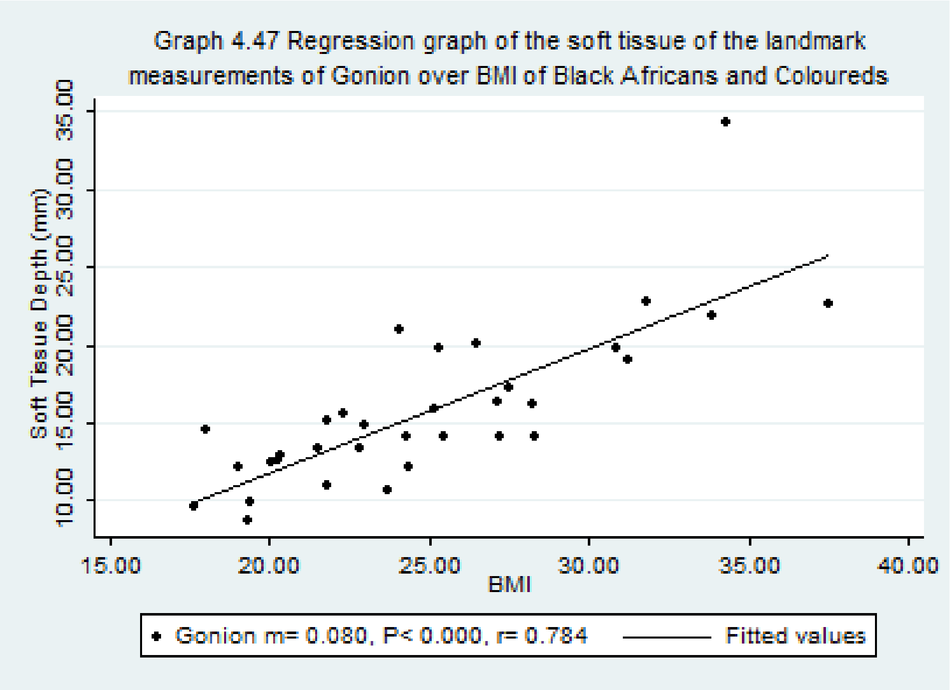
Table 4.13 Regression values of soft tissue measurements of Black African and Coloured participants and BMI (kg/m^2), ordered by gradient.

Mot= Maximum Occipital Point, m= gradient

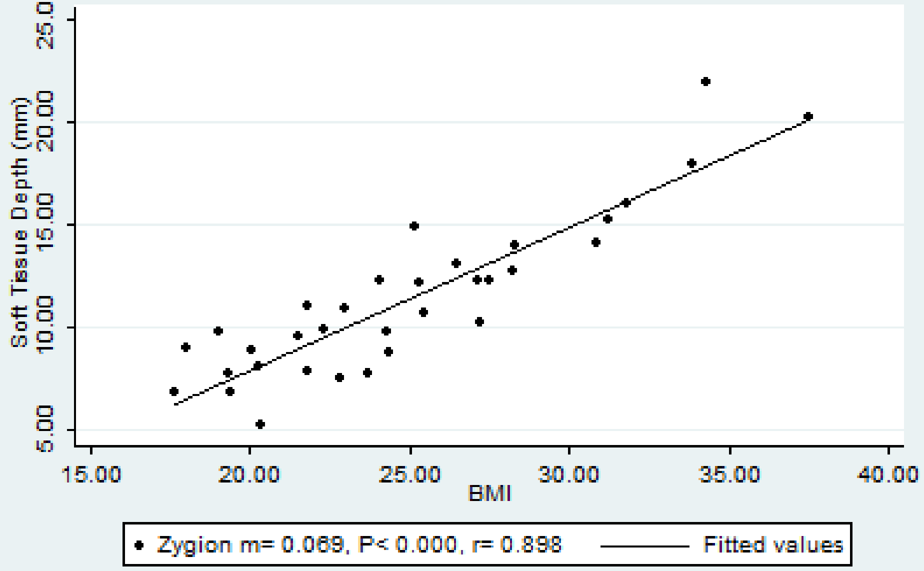
Landmarks	m-value	P-value	r-value	R-squared
Go	0.080	P< 0.000	0.784	0.615
Z	0.069	P< 0.000	0.898	0.807
Gn	0.046	P< 0.000	0.774	0.600
Po	0.033	0.001	0.538	0.290
E	0.028	P< 0.000	0.595	0.355
Mot	0.026	P< 0.000	0.719	0.518
Mp	0.019	0.153	0.254	0.065
In	0.018	P< 0.000	0.630	0.397
G	0.016	P< 0.000	0.679	0.461
Op	0.014	P< 0.000	0.653	0.426
N	0.014	0.023	0.394	0.155
V	0.012	0.006	0.466	0.217
R	0.011	P< 0.000	0.632	0.400
Ml	0.010	0.123	0.274	0.075

Nt	0.008	0.532	0.113	0.013
Pr	0.007	0.208	0.225	0.051
Sm	0.003	0.704	0.069	0.005

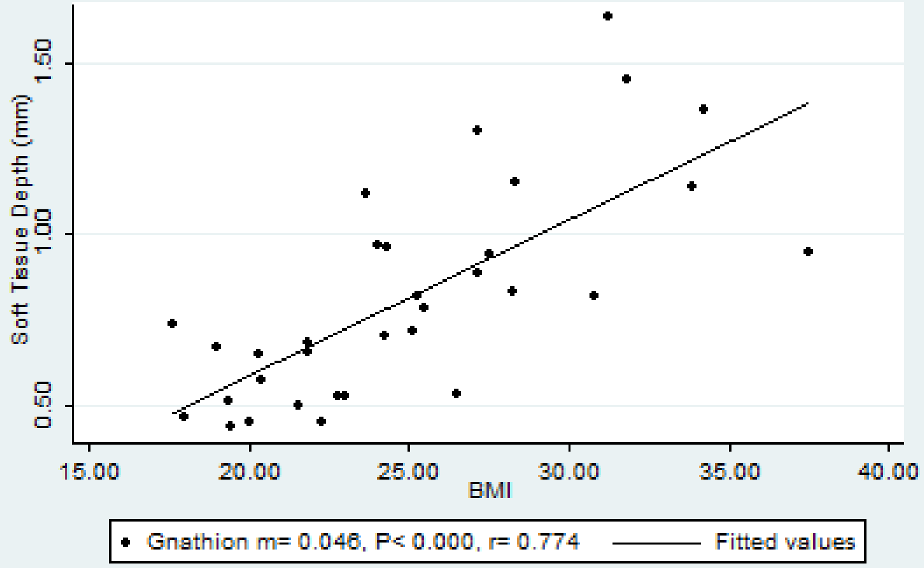
Gonion (Graph 4.47) had the highest gradient (m= 0.080) and second strongest correlation (r= 0.784). Zygion (Graph 4.48) had the second highest gradient (m= 0.069) and the strongest correlation (r= 0.898). Gnathion (Graph 4.49) had the third highest gradient (m= 0.046) and was strongly correlated (r= 0.774). Pogonion (Graph 4.50) had the 4th highest gradient (m= 0.033) and was moderately correlated (r= 0.538). Maximum Occipital Point was the fourth strongest correlation (r= 0.719), but sixth highest gradient (m= 0.026).

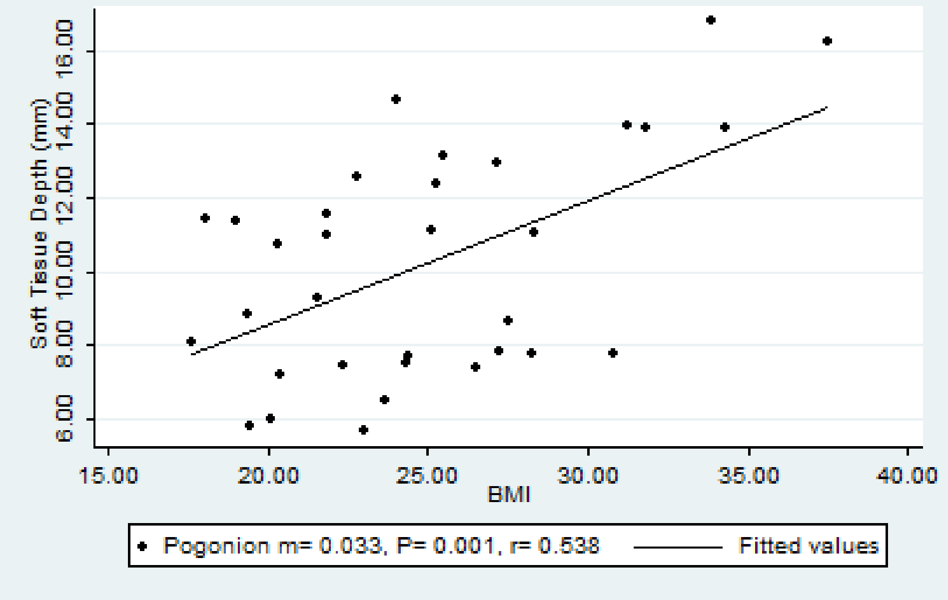

Graph 4.47 Regression graph of the soft tissue of the landmark measurements of Gonion over BMI of Black Africans and Coloureds

Graph 4.48 Regression graph of the soft tissue of the landmark measurements of Zygion over BMI of Black Africans and Coloureds



Graph 4.49 Regression graph of the soft tissue of the landmark measurements of Gnathion over BMI of Black Africans and Coloureds





Graph 4.50 Regression graph of the soft tissue of the landmark measurements of Pogonion over BMI of Black African and Coloureds

The correlation of the measurements was significant for all landmarks but Mid-philtrum, Mid-lip, Nasal tip, Prosthion and Supra-mentale.

When compared to the body fat percentage results (Chapter 4.2.3.2.1), Pogonion and Maximum Occipital Point switched positions between fourth and sixth highest gradient. Euryon remained in fifth position. And Pogonion was significantly correlated with BMI, unlike with body fat percentage. The correlation values also tended to increase when the landmark measurements were correlated with BMI.

4.4.4.2.2. WHITES

4.4.4.2.2.1. BODY FAT PERCENTAGE REGRESSION ANALYSIS OF WHITES

The landmark measurements of the White participants (Summarized in Table 4.14) results showed five of the 17 landmarks were significant. Gonion, Zygion, Pogonion and Gnathion had the highest four gradients again, but only Gonion, Zygion and Pogonion had significant correlation values.

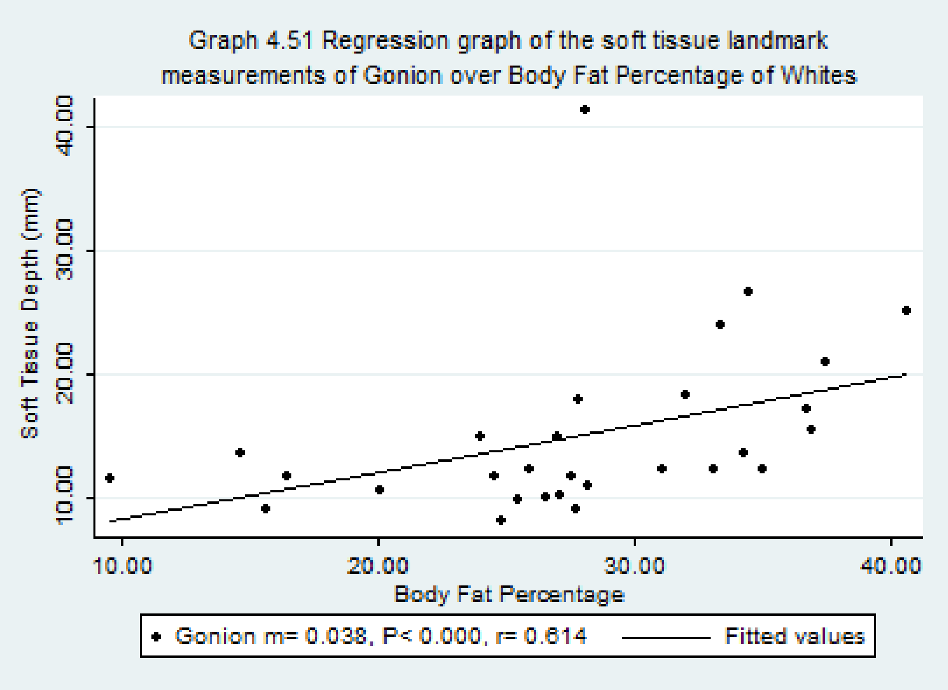
Table 4.14 Regression values of soft tissue measurements of White participants and Body Fat Percentage, ordered by gradient.

Mot= Maximum Occipital Point, m= gradient

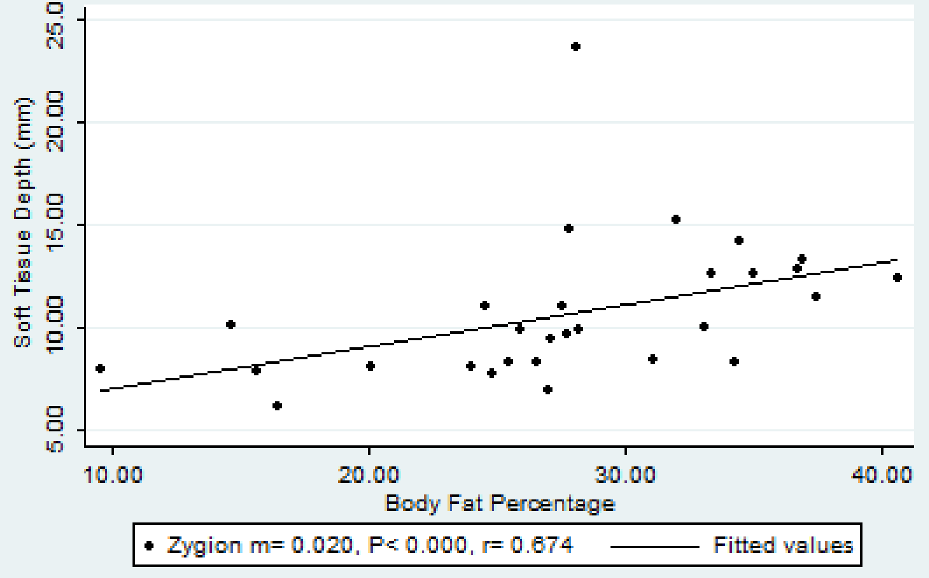
Landmarks	m-value	P-value	r-value	R-squared
Go	0.038	P< 0.000	0.614	0.377
Z	0.020	P< 0.000	0.674	0.454
Po	0.014	0.024	0.419	0.175
Gn	0.011	0.094	0.317	0.101
N	0.004	0.061	0.352	0.124
G	0.003	0.244	0.224	0.050
Sm	0.003	0.728	0.068	0.005
In	0.002	0.649	0.088	0.008
Op	0.002	0.647	0.089	0.008
V	0.001	0.821	0.044	0.002
E	-0.001	0.858	0.035	0.001
Mot	-0.001	0.732	0.066	0.004
R	-0.002	0.581	0.107	0.011
Ml	-0.008	0.212	0.239	0.057
Nt	-0.013	0.133	0.122	0.015

Pr	-0.016	0.033	0.396	0.157
Mp	-0.016	0.038	0.388	0.150

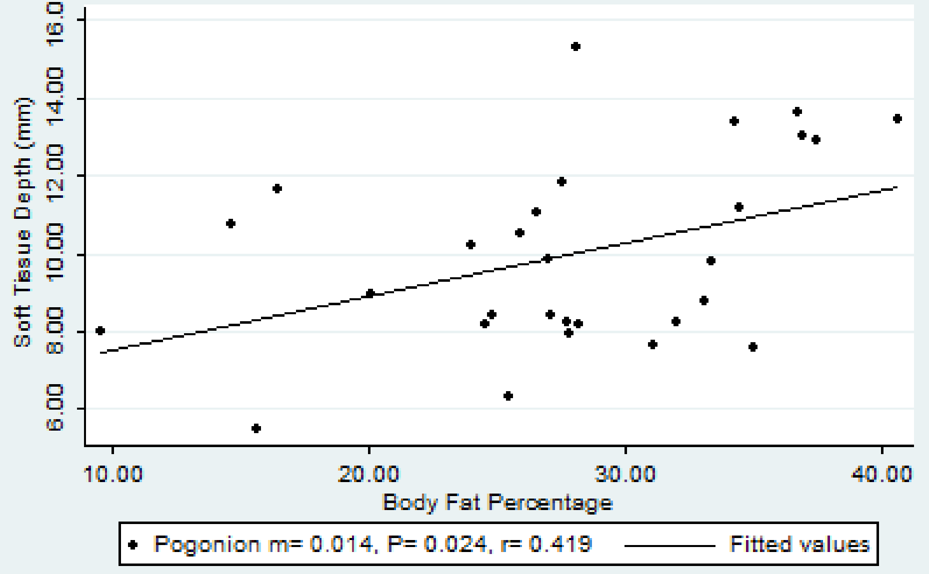
Gonion (Graph 4.51) had the greatest gradient (m= 0.040), while Zygion (Graph 4.52) had the highest correlation (r= 0.693). Both were moderately correlated (r= 0.614 and r= 0.674, respectively) to body fat percentage. Pogonion (Graph 4.53) was the third highest gradient (m=0.014) that was significant, with a weak to moderate correlation (r= 0.419).

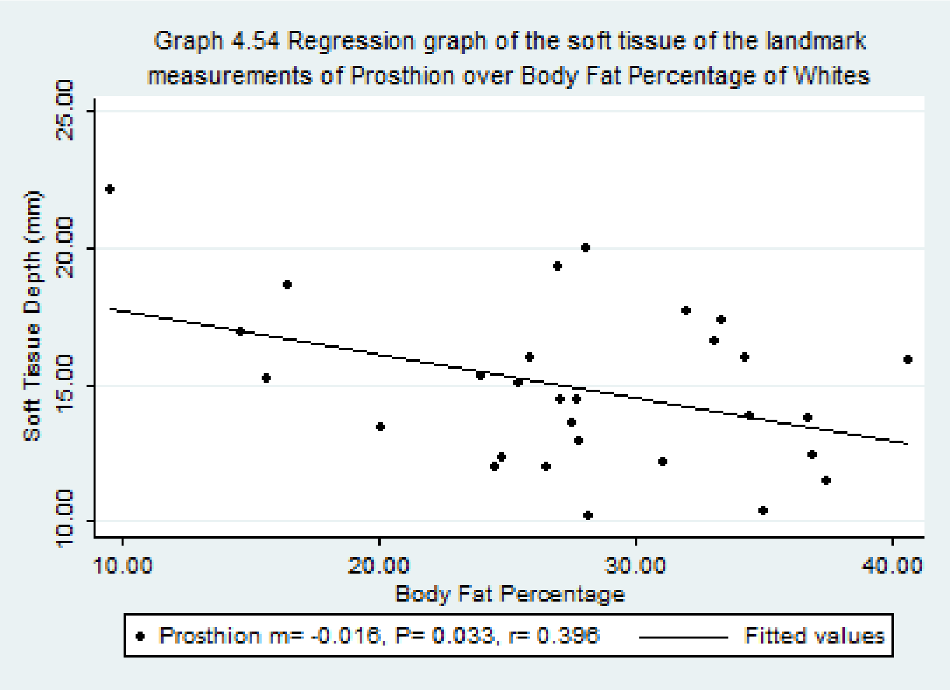

Graph 4.51 Regression graph of the soft tissue landmark measurements of Gonion over Body Fat Percentage of Whites

Graph 4.52 Regression graph of the soft tissue of the landmark measurements of Zygion over Body Fat Percentage of Whites

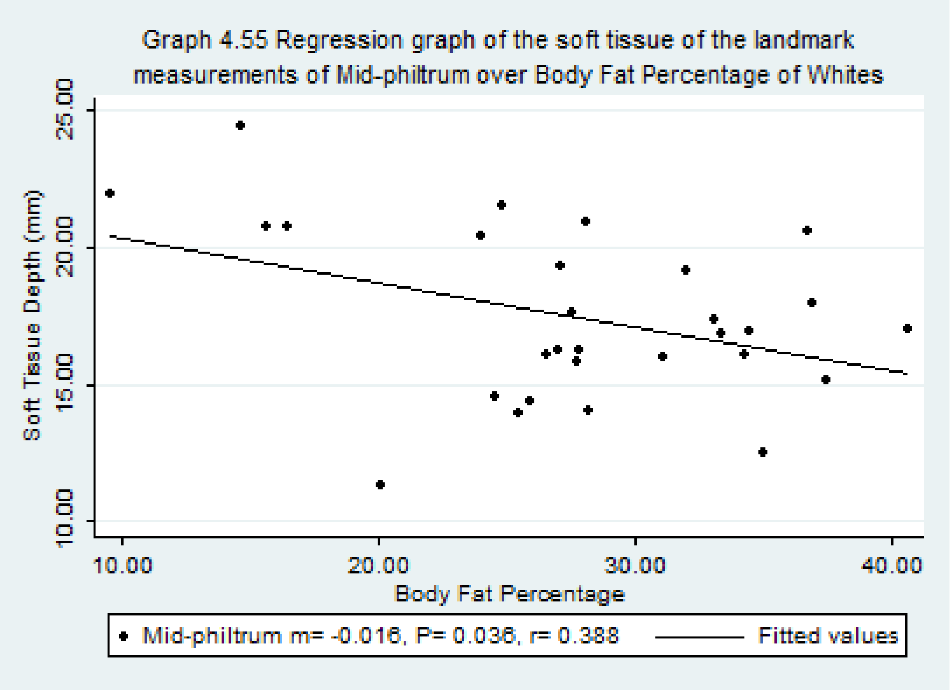


Graph 4.53 Regression graph of the soft tissue of the landmark measurements of Pogonion over Body Fat Percentage of Whites





Graph 4.54 Regression graph of the soft tissue of the landmark measurements of Prosthion over Body Fat Percentage of Whites



Graph 4.55 Regression graph of the soft tissue of the landmark measurements of Mid-philtrum over Body Fat Percentage of Whites

Prosthion (Graph 4.54) and Mid-philtrum (Graph 4.55) had negative gradients (m= -0.016 both) which were weakly correlated (r= 0.396 and r= 0.388, respectively).

When comparing the regression values of Black African and Coloured participants with White participants, the top two significant landmarks were the same (Gonion and Zygion). Pogonion was the other significant landmark the two groups shared, though it was third in Whites and sixth in Black African and Coloureds. Gnathion for both groups was not significantly correlated with body fat percentage.

There was one outlier for Gonion, one for Zygion, one for Pogonion and one for Mid-philtrum. The outlier seen in Gonion, Zygion and Pogonion are from the same individual and the same as seen in the previous chapters.

4.4.4.2.2.2. BMI REGRESSION ANALYSIS OF WHITES

Table 4.15 summarized the results of the regression analysis of White participants with BMI. Ten of the 17 landmarks were found to be significant of which Gonion, Gnathion, Zygion and Pogonion had the greatest four gradients, as in the previous regression tests.

Gonion (Graph 4.56) had the greatest gradient (m= 0.089) and second strongest correlation (r= 0.743). Gnathion (Graph 4.57) had the second highest gradient (m= 0.043) and a weak to moderate correlation (r= 0.471). Zygion (Graph 4.58) had the third highest gradient (m= 0.040) and was moderately correlated (r= 0.550). Pogonion had the fourth highest gradient (m= 0.029) and was moderately correlated (r= 0.518). Nasion and Glabella had strong correlations (r= 0.757 and r= 0.739, respectively) and were significant ($P > 0.05$)

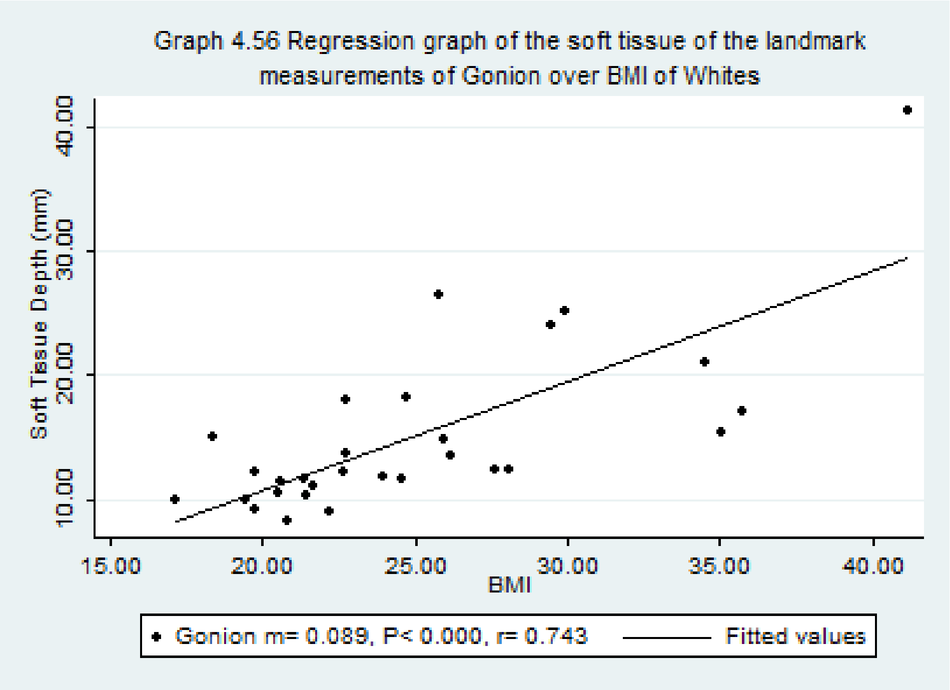
The correlation of the measurements was significant for all landmarks but Mid-lip, Supra-mentale, Inion, Mid-philtrum, Rhinion, Prosthion and Nasal tip.

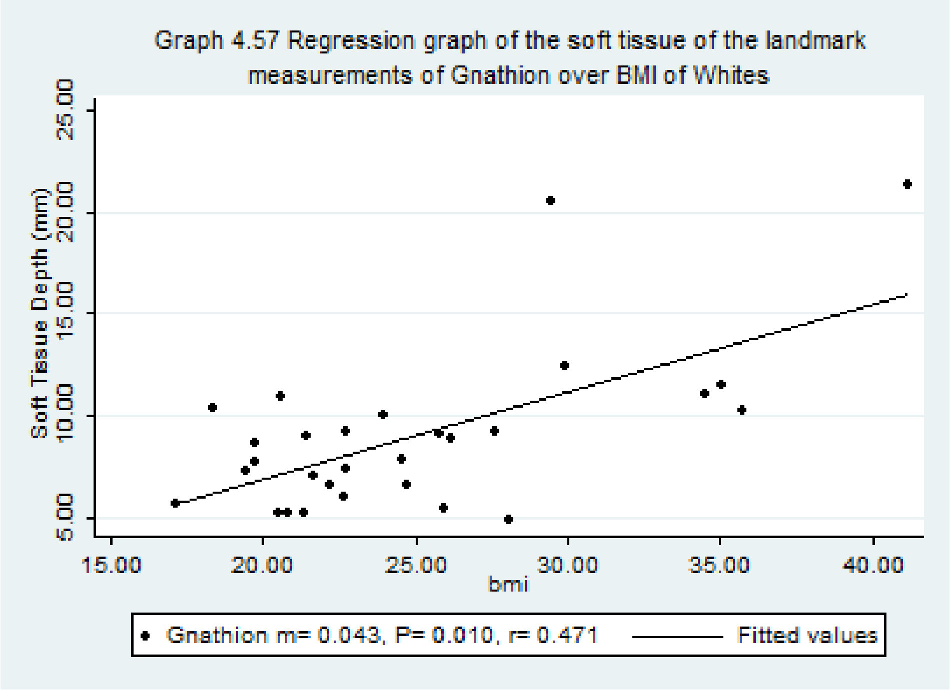
Table 4.15 Regression values of soft tissue measurements of White participants and BMI (kg/m^2), ordered by gradient.

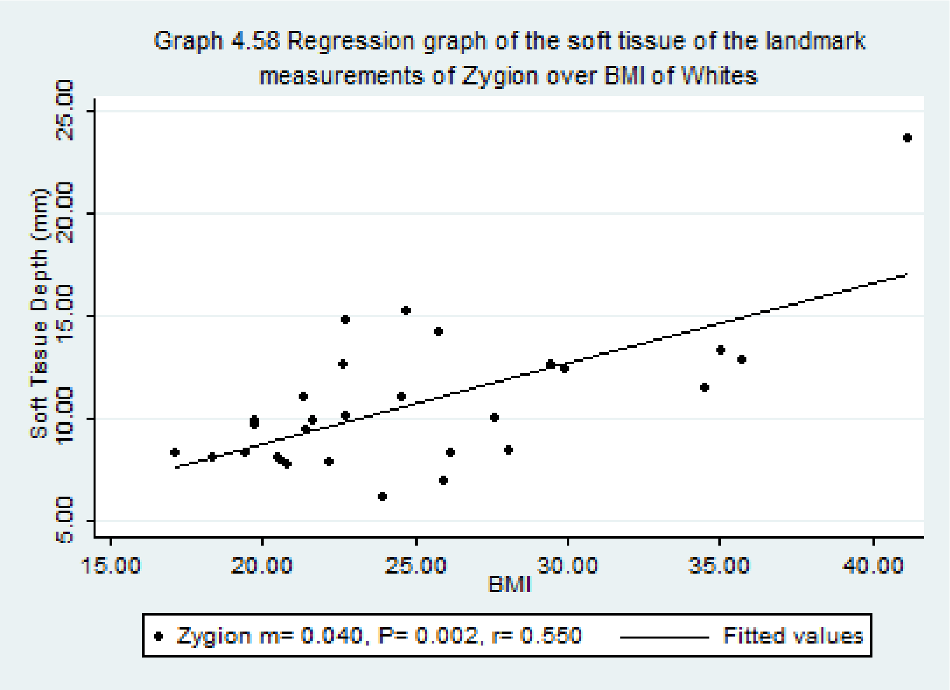
Mot= Maximum Occipital Point, m= gradient

Landmarks	m-value	P-value	r-value	R-squared
Go	0.089	P< 0.000	0.743	0.552
Gn	0.043	0.010	0.471	0.222
Z	0.040	0.002	0.550	0.302
Po	0.029	0.004	0.518	0.268
N	0.023	P< 0.000	0.757	0.574
Mot	0.015	0.006	0.496	0.246
Op	0.015	P< 0.000	0.688	0.474
Ml	0.015	0.174	0.259	0.067
G	0.015	P< 0.000	0.739	0.545
Sm	0.014	0.367	0.050	0.003
In	0.013	0.052	0.365	0.133
V	0.013	0.002	0.554	0.307
E	0.011	0.032	0.400	0.160
Mp	0.009	0.242	0.224	0.050
R	0.009	0.960	0.473	0.224

Pr	0.007	0.422	0.155	0.024
Nt	-0.005	0.720	0.070	0.005


Graph 4.56 Regression graph of the soft tissue of the landmark measurements of Gonion over BMI of Whites


Graph 4.57 Regression graph of the soft tissue of the landmark measurements of Gnathion over BMI of Whites


Graph 4.58 Regression graph of the soft tissue of the landmark measurements of Zygion over BMI of Whites

Unlike with body fat percentage, Gnathion is significantly correlated with BMI. Pogonion shifted position from third to fourth position, and Zygion from second to third.

Comparing the regression values of the Black African and Coloured participants and White participants with BMI; Inion and Vertex were significant for Black African and Coloureds but not for Whites. The strongest significant correlations (r> 0.7) for Black African and Coloureds were Gonion, Zygion, Gnathion and Maximum Occipital Point, while only Gonion was significant and strongly correlated for Whites.

4.4.4.3. ANCESTRY GROUP COMPARISONS

Both ancestry groups, irrespective of body fat percentage or BMI, showed that changes to fatness affected Gonion the most. The increase was less with body fat percentage but correlation was high for both measures of fatness.

Zygion was the second most affected by changes in fatness for both groups, though Gnathion was slightly more so in the White group when correlated to BMI.

Body fat percentage had less impact than BMI for both groups, as Gnathion had no significant relationship with it. Yet, when correlated with BMI, the relationship was significant.

While both groups showed that fatness had significant influence around the lower face and jaw, Black African and Coloureds were also affected by changes in fatness around the cranium and upper face. This is interesting as when determining ancestry for the biological profile, a more prognathic or projecting mandible and maxilla are indications of possible African ancestry. Whites were also affected by changes in fatness around the upper face.

4.5. BMI COMPARISONS

Table 4.16 summarizes the sex and population distribution for BMI under 25kg/m^2 and BMI over 25kg/m^2. Those with a BMI under 25kg/m^2 were of a normal or underweight weight category, while those with a BMI over 25kg/m^2 were of an overweight or obese weight category.

Table 4.16 Distribution table of BMI by Sex and Ancestry

Sample Divisions	**BMI<25kg/m^2**	**BMI>25kg/m^2**
Total	39	28
Females	28	22
Males	11	6
Black African and Coloured	18	11
White	18	15
Other	3	2

The differences of the BMI groups, sexes and population groups were tested for each landmark measurement and the results for the T-tests were summarized in Table 4.17. The results that fell under 0.05 indicated that it was describing two separate groups. 41.79% of the sample had a BMI over 25kg/m^2, falling into the overweight or obese weight category.

4.5.1. BMI UNDER 25 AND BMI OVER 25 COMPARISON

A T-test was performed to compare the landmark measurements for BMI under 25kg/m^2 and BMI above 25kg/m^2.

When comparing the 2 BMI groups, only the landmark measurements around the lips and tip of the nose were found not to be significant. This indicated that they were two separate groups, with the change in BMI affecting the tissue depth measurements of each landmarks except for Nasal Tip, Mid-philtrum, Prosthion, Mid-lip and Supra-mentale.

The t-values of the significant landmarks all showed strong (Euryon and Nasion) to very strong (Zygion, Gonion, Vertex, Maximum Occipital Point, Rhinion, Inion, Pogonion, Gnathion, Ophryon and Glabella) evidence of there being a difference between the two groups.

4.5.2. MALE AND FEMALE COMPARISON

A T-test was performed to compare the landmark measurements for males and females. The differences between the male and female groups were found to only be significant around the upper nose (Nasion and Rhinion) and mouth (Mid-philtrum, Prosthion, Mid-lip and Inion) regions of the face. Euryon was also found to be significant when comparing the sexes, the only lateral width measurement that was. This indicated that there was a difference between the means of those landmark measurements between the sexes.

The t-values of the significant landmarks all showed strong (Euryon, Rhinion and Inion) to very strong (Mid-philtrum, Prosthion, Mid-lip and Nasion) evidence of there being a difference between the 2 sexes.

Note that the Supra-mentale, Mid-philtrum and Mid-lip were found not to be significant between the two BMI groups too.

Table 4.17 T-value and P-value results of T-tests
Mot= Maximum Occipital Point

Facial Region	**Measurements**	**BMI<25kg/m^2 vs BMI>25kg/m^2**		**Male vs Female**		**Black African and Coloured vs White**	
		P-value	**t-value**	**P-value**	**t-value**	**P-value**	**t-value**
Lateral	**E**	**0.003**	2.994	**0.031**	-2.161	0.001	3.623
	Z	**0.000**	5.174	0.226	1.210	0.587	-0.543
	Go	**0.000**	5.549	0.634	0.475	0.139	-1.481
Cranium	**Mot**	**0.000**	-3.877	0.098	1.680	**0.000**	-3.887
	V	**0.001**	-3.413	0.427	0.799	**0.000**	6.028
Brow	**Op**	**0.000**	5.074	0.167	-1.384	0.895	0.133
	G	**0.000**	-5.505	0.079	1.787	0.875	0.158
Upper Nose	**R**	**0.002**	3.064	**0.007**	-2.688	**0.004**	-2.871
	N	**0.007**	2.708	**0.004**	3.017	**0.015**	2.427
Nose Tip	**Nt**	0.400	-0.848	0.074	1.818	**0.003**	-3.071
Mouth	**Mp**	0.121	1.551	0.000	4.833	0.769	0.295

	Pr	0.353	0.928	**0.000**	4.798	0.262	1.122
	Ml	0.645	-0.463	**0.000**	4.476	0.185	1.341
	In	**0.002**	-3.311	**0.007**	-2.688	0.853	0.186
	Sm	0.137	-1.508	0.123	-1.542	0.833	-0.212
Chin	**Po**	**0.000**	-4.928	0.795	-0.259	0.696	0.393
	Gn	**0.000**	4.399	0.113	-1.585	0.378	0.882

4.5.3. BLACK AFRICAN AND COLOURED AND WHITE COMPARISON

A T-test was performed to compare the landmark measurements for Black African and Coloured participants and White participants.

The differences between the Black African and Coloured, and White groups were found to be significant around the cranium (Maximum Occipital Point and Vertex) and nose (Nasion, Rhinion and Nasal Tip) regions of the face. Euryon was also found to be significant when comparing the sexes, the only lateral width measurement that was.

The t-values of the significant landmarks all showed strong (Rhinion and Nasion) to very strong (Euryon, Vertex, Maximum Occipital Point, and Nasal Tip) evidence of there being a difference between the two ancestry groups.

Again, Supra-mentale was not significant for differences between the two population groupings, as with the tests between the sexes and two BMI groups.

4.5.4. SEQUENTIAL BONFERRONI METHOD

The sequential Bonferroni method was applied to the P-values of the T-tests, summarized in table 4.18. The results showed no changes for which landmarks were found to be significant in the T-tests.

Table 4.18 P-values adjusted using the sequential Bonferroni method

Landmarks	**BMI<25kg/m^2 vs BMI>25kg/m^2**	**Landmarks**	**Male vs Female**	**Landmarks**	**Black African and Coloured vs White**
Z	0.000	Mp	0.000	Mot	0.000
Go	0.000	Pr	0.000	V	0.000
Mot	0.000	Ml	0.000	E	0.004
Op	0.000	N	0.016	Nt	0.009
G	0.000	R	0.021	R	0.008
Po	0.000	In	0.014	N	0.015
Gn	0.000	E	0.031		
V	0.005				
R	0.008				
In	0.006				
E	0.006				
N	0.007				

4. 6. ANALYSIS OF THE VARIANCES

4.6.1. COEFFICIENTS OF VARIATION

The low sample size makes analysis difficult, as subdividing the data by multiple factors decreases the size significantly. This is especially the case when comparing the sexes and ancestry groups. The percentage of males and females in Black Africans and Coloureds is not the same as in Whites. To compare the different values another means was needed.

Table 4.19 Coefficients of Variation of Total Sample

Groups		Ancestry combined	Black African and Coloured combined	White
Landmarks	Pairwise Comparisons	Male and Female	Male and Female	Male and Female
E	Male	21.65	22.93	20.14
	Female	25.14	21.39	22.53
Z	Male	43.06	32.87	63.95
	Female	31.59	33.94	22.83
Go	Male	47.87	25.56	76.86
	Female	38.64	32.06	35.44
V	Male	15.73	13.51	19.48
	Female	26.43	16.84	24.41
Mot	Male	19.70	**19.47**	22.54
	Female	22.76	**19.01**	19.16
R	Male	29.21	20.08	40.38
	Female	31.79	26.43	25.03
Nt	Male	13.54	14.06	12.98
	Female	11.69	12.39	10.32

Mp	Male	18.60	**21.85**	7.22
	Female	15.89	**21.03**	15.12
Pr	Male	15.35	11.97	14.38
	Female	14.04	12.98	16.63
Ml	Male	26.15	23.61	25.52
	Female	36.61	29.65	39.93
In	Male	11.82	9.54	16.80
	Female	13.94	12.52	15.20
Sm	Male	14.04	15.03	11.54
	Female	16.87	12.69	17.85
Po	Male	31.66	**31.16**	36.54
	Female	26.86	**30.39**	22.09
Gn	Male	38.62	25.42	48.93
	Female	44.79	38.69	40.29
Op	Male	18.82	12.98	24.19
	Female	20.15	16.38	15.65
G	Male	17.50	**17.07**	18.24
	Female	16.34	**16.56**	14.37
N	Male	26.06	**23.09**	28.67
	Female	17.33	**22.14**	13.31

The coefficient of variation was calculated for each landmark, separated into different paired comparisons. The results of the ancestry group data divided by sex are summarized in Table 4.19.

There are low differences between co-variances (< 1) for six of the 17 landmarks, but only for the Black African and Coloured sample.

The results of the ancestry group and sex data, compared by BMI, are summarized in Table 4.20. BMI was divided at 25kg/m^2, the cut-off between normal and overweight BMI (Centers for Disease Control and Prevention).

Table 4.20 Coefficients of Variation of Total Sample divided by BMI

Groups		**Sex and Ancestry combined**	**Black African and Coloured combined**	**White**	**Male and Ancestry Combined**	**Female and Ancestry Combined**
Landmarks	**Pairwise Compa-risons**	**<25>**	**<25>**	**<25>**	**<25>**	**<25>**
E	**<25**	22.22	19.82	**23.53**	21.65	18.10
	>25	23.47	18.74	**22.82**	10.69	26.12
Z	**<25**	23.37	19.75	32.50	43.06	22.75
	>25	29.23	23.04	36.50	34.94	27.84
Go	**<25**	21.97	21.44	46.30	47.87	21.48
	>25	36.46	26.90	42.60	50.38	32.78
V	**<25**	23.15	13.56	23.89	15.73	25.24
	>25	21.17	16.96	19.34	11.80	23.36
	<25	18.15	14.14	**21.80**	19.70	17.93

Mot	**>25**	21.83	16.23	**22.50**	15.41	22.97
R	**<25**	31.17	20.46	**38.91**	29.21	**29.54**
	>25	29.84	22.64	**38.23**	27.73	**28.62**
Nt	**<25**	**12.84**	11.71	**10.67**	13.54	**11.92**
	>25	**11.92**	13.00	**10.55**	11.60	**11.56**
Mp	**<25**	20.44	19.33	17.71	18.60	15.01
	>25	18.26	22.23	10.63	16.16	16.09
Pr	**<25**	**16.92**	11.59	**19.63**	**15.35**	12.75
	>25	**16.56**	14.41	**18.66**	**16.18**	14.90
Ml	**<25**	36.17	22.74	**46.34**	26.15	34.94
	>25	39.86	37.01	**45.86**	28.16	38.90
In	**<25**	12.19	12.19	15.92	**11.82**	11.46
	>25	13.92	9.45	18.28	**11.78**	13.94
Sm	**<25**	13.46	11.07	17.09	14.04	14.03
	>25	18.78	14.43	18.26	20.65	18.75
Po	**<25**	**24.36**	28.88	24.48	31.66	21.08
	>25	**23.58**	27.04	20.63	24.87	23.41
Gn	**<25**	28.07	**30.95**	43.97	38.62	25.45
	>25	39.63	**30.14**	46.96	43.93	39.34
Op	**<25**	15.54	15.53	19.61	18.82	14.11
	>25	17.25	12.88	16.00	21.90	16.30

G	**<25**	**14.37**	15.75	16.27	17.50	12.47
	>25	**13.73**	12.55	14.52	20.84	11.41
N	**<25**	19.45	24.71	19.53	26.06	16.43
	>25	21.79	18.29	21.09	32.50	14.70

The occurrences of low differences between co-variances (< 1) were more common when the sample was divided to compare the 2 BMI groups. When the whole sample was divided by BMI; Nasal tip, Prosthion, Pogonion and Glabella had low differences between co-variances, indicating that the differences for those landmarks differed the least between the two groups.

There were greater differences between the co-variances of the Black African and Coloureds group, where Gnathion was the only landmark with low differences between the co-variances. Whites had more low differences between co-variances with six landmarks having a difference under one.

The sexes both had two points of low differences between co-variance, Prosthion and Inion (around the mouth region) for males and Rhinion and Nasal tip (around the nasal region) for females. In males this indicated that the soft tissues of the mouth changed less with low or high BMI's. In females this indicated that the soft tissues of the nose changed less with low or high BMI's.

The results of the ancestry group and sex data, compared by body fat percentage, are summarized in Table 4.21. Body fat percentage was divided at the point of 25% for males and 32% for females, the cut-offs between normal and overweight BMI (Muth 2009).

When the whole sample was divided by body fat percentage; Nasal tip, Prosthion, Inion and Nasion had low differences between co-variances, indicating that the differences for those landmarks differed the least between the two groups. Nasal tip and Prosthion were two of the landmarks with differences under one for BMI too.

Black African and Coloureds had no landmarks with low differences between co-variance, while Whites had a lower difference between the co-variance of Glabella. This indicated that, except at Glabella for Whites, both ancestry groups exhibited differences at all landmarks between low and high body fat percentages. Females only had low differences between co-variances at the Nasal tip, Mid-philtrum and Glabella, while males had none. In females this indicated that the soft tissues of the lower nose and brow were less affected by low or high BMI's.

Table 4.21 Coefficients of Variation of Total Sample Divided by Body Fat Percentage

Groups		**Sex and Ancestry combined**	**Black African and Coloured combined**	**White**	**Male and Ancestry Combined**	**Female and Ancestry Combined**
Landmarks	**Pairwise Comparisons**	**<25> (male) & <32> (female)**	**<25> (male) & <32> (female)**	**<25> (male) & <32> (female)**	**<25> (male) & <32> (female)**	**<25> (male) & <32> (female)**
E	**Low Body Fat %**	21.60	17.39	24.02	17.45	22.55
	High Body Fat %	27.20	22.76	22.79	23.62	26.15
Z	**Low Body Fat %**	27.05	28.12	25.00	33.54	24.22
	High Body Fat %	28.82	24.60	33.96	44.74	26.56
Go	**Low Body Fat %**	23.91	23.20	33.85	24.57	23.85
	High Body Fat %	37.65	27.45	43.10	46.18	34.48
V	**Low Body Fat %**	22.85	15.46	22.63	15.68	25.75

	High Body Fat %	25.86	14.11	23.67	3.17	27.33
Mot	**Low Body Fat %**	19.50	15.68	19.71	18.51	19.19
	High Body Fat %	25.22	14.46	24.55	6.75	25.70
R	**Low Body Fat %**	30.61	22.89	34.04	25.44	30.31
	High Body Fat %	34.47	26.53	46.43	31.02	31.38
Nt	**Low Body Fat %**	**12.76**	12.65	10.13	12.39	**11.94**
	High Body Fat %	**11.81**	8.97	12.54	13.71	**11.28**
Mp	**Low Body Fat %**	21.21	22.13	18.65	19.25	**15.76**
	High Body Fat %	15.12	16.83	13.38	13.96	**15.33**
Pr	**Low Body Fat %**	**16.69**	13.83	19.41	14.43	13.33
	High Body Fat %	**17.34**	6.15	23.03	28.91	15.36
Ml	**Low Body Fat %**	38.79	30.47	47.23	24.71	38.56
	High Body Fat %	35.36	27.49	32.03	41.69	32.04

In	**Low Body Fat %**	**12.64**	12.86	15.74	10.95	10.76
	High Body Fat %	**13.14**	4.63	9.01	14.97	12.89
Sm	**Low Body Fat %**	14.54	13.14	18.09	13.56	14.03
	High Body Fat %	17.26	9.41	12.41	23.72	17.30
Po	**Low Body Fat %**	25.54	28.58	20.22	31.02	21.71
	High Body Fat %	23.63	7.74	7.08	3.14	24.26
Gn	**Low Body Fat %**	28.36	30.52	39.90	24.39	26.60
	High Body Fat %	39.71	21.18	34.22	53.01	38.28
Op	**Low Body Fat %**	16.52	**15.80**	16.48	14.80	16.46
	High Body Fat %	21.10	**14.97**	21.51	32.20	19.95
G	**Low Body Fat %**	15.69	16.89	**13.02**	16.21	**13.69**
	High Body Fat %	14.42	9.55	**12.84**	21.44	**13.48**

N	**Low Body Fat %**	**20.82**	24.38	12.20	20.06	17.43
	High Body Fat %	**20.68**	7.94	24.37	54.14	10.60

4.6.2. LEVENE'S TEST ANALYSIS

A Levene's F test was used to look at the homogeneity of the variance. The results are summarized in Table 4.22 to 4.24, with the significant results highlighted. Only Vertex and Nasion had significant differences between the two sexes of the total sample (P=0.042 and P= 0.017, respectively). When the sexes are compared divided by ancestry group, Rhinion was the only landmark that showed significant differences in the White ancestry group.

When comparing the sexes and ancestry groups, divided by BMI under and over 25kg/m^2, there are few significant differences. The variation of Zygion (P= 0.032), Gonion (P= 0.001), Maximum Occipital Point (P= 0.024) and Gnathion (P= 0.007) showed significant differences between the 2 BMI groups, for the total sample. This indicated that the variation was significantly different between individuals of different fatnesses. These 3 landmarks were also landmarks which were significant in regression analysis (Chapter 4.2 Analysis of Total Sample) for the total sample, sexes and ancestry groups. The variation of Euryon (P= 0.019),Gonion (P= 0.004), Maximum Occipital Point (P= 0.024) and Gnathion (P= 0.005) were significant for the sample of female participants. This indicated that there was a significant difference at those points (the lower jaw and back of the cranium) between individuals who fell into the underweight and normal group and those who fell into the overweight and obese group. The variance between the 2 BMI groups was not significant for any other landmark, for males, or either ancestry group.

Table 4.22 P-values of Levene's F Test of Variances, Sex Comparisons

Landmarks	**N**	**G**	**Op**	**Gn**	**Po**	**Sm**	**In**	**Ml**	**Pr**	**Mp**	**Nt**	**R**	**Mot**	**V**	**Go**	**Z**	**E**
Ancestry combined	**0.017**	0.416	0.904	0.652	0.320	0.942	0.571	0.741	0.197	0.113	0.129	0.634	0.997	**0.042**	0.871	0.677	0.977
Black African and Coloured combined	0.356	0.657	0.281	0.313	0.922	0.342	0.156	0.992	0.818	0.415	0.217	0.362	0.885	0.299	0.418	0.611	0.776
White	0.065	0.562	0.133	0.505	0.237	0.230	0.862	0.970	0.871	0.271	0.504	**0.002**	0.505	0.681	0.328	0.183	0.778

Table 4.23 P-values of Levene's F Test of Variances, BMI Comparisons

Landmarks	**N**	**G**	**Op**	**Gn**	**Po**	**Sm**	**In**	**Ml**	**Pr**	**Mp**	**Nt**	**R**	**Mot**	**V**	**Go**	**Z**	**E**
Sex and Ancestry combined	0.638	0.393	0.293	**0.007**	0.136	0.107	0.383	0.553	0.750	0.906	0.911	0.290	**0.024**	0.466	**0.001**	**0.032**	0.057
Black African and Coloured combined	0.522	0.886	0.837	0.127	0.465	0.274	0.672	0.090	0.454	0.223	0.526	0.181	0.138	0.164	0.116	0.072	0.167
White	0.719	0.812	0.640	0.385	0.925	0.794	0.601	0.849	0.998	0.069	0.870	0.822	0.993	0.635	0.386	0.663	0.578
Male and Ancestry Combined	0.558	0.552	0.672	0.549	0.650	0.152	0.730	0.774	0.732	0.545	0.435	0.773	0.894	0.524	0.419	0.673	0.148
Female and Ancestry Combined	0.913	0.489	0.248	**0.005**	0.052	0.296	0.185	0.531	0.310	0.476	0.549	0.318	**0.025**	0.351	**0.004**	0.114	**0.019**

Table 4.24 P-values of Levene's F Test of Variances, Body Fat Percentage Comparisons

Landmarks	**N**	**G**	**Op**	**Gn**	**Po**	**Sm**	**In**	**Ml**	**Pr**	**Mp**	**Nt**	**R**	**Mot**	**V**	**Go**	**Z**	**E**
Sex and Ancestry combined	0.485	0.921	0.139	**0.000**	0.670	0.418	0.911	0.654	0.853	0.250	0.753	0.273	**0.019**	0.230	**0.000**	0.097	0.072
Black African and Coloured combined	**0.024**	0.156	0.763	0.606	**0.043**	0.269	0.097	0.838	0.153	0.837	0.267	0.559	0.731	0.890	0.244	0.345	**0.026**
White	0.090	0.986	0.312	0.736	0.144	0.308	0.288	0.840	0.891	0.537	0.683	0.330	0.609	0.447	0.087	0.524	0.710
Male and Ancestry Combined	**0.001**	0.423	**0.016**	**0.000**	0.110	0.355	0.473	0.145	0.204	0.571	0.573	0.295	0.365	0.180	**0.000**	0.064	0.202
Female and Ancestry Combined	0.146	0.516	0.236	**0.001**	0.218	0.376	0.360	0.656	0.288	0.627	0.796	0.492	**0.031**	0.488	**0.003**	0.155	0.212

5. DISCUSSION

5.1. SUMMARY OF RESULTS: THE RELATIONSHIP BETWEEN BMI, BODY FAT PERCENTAGE AND SOFT TISSUE THICKNESSES

This study showed that when comparing all the facial landmarks, without division by sex or ancestry group, that body fat percentage does indeed have an effect on the measurements at some of the landmarks. The effect is most strongly seen on the landmarks associated with facial widths and the chin, those being Zygion, Gonion, Pogonion and Gnathion (pages 88 and 93).

Of those landmarks, Gonion and Zygion were the most strongly affected with Gonion having the greatest change as body fat percentage increased (page 88). This indicated that facial fatness is mostly gained along the lateral aspects of the face, around the cheeks, jaw and chin; more than along the midline or profile regions of the face which displayed little or no change as body fat increased.

A greater number of the landmark measurements of the females of the sample were influenced by an increase in body fat percentage than the males. The female face changed most with increased body fat, particularly in the chin, jaw, cheek, brow and lower lip regions (page 99). The males face was more influenced at the chin, jaw, cheek and temporal regions (page 108).

When the data are divided between two population groupings (Black African/ Coloured and White) the influence of fatness is most strongly seen, again, in the landmarks associated with facial widths. Black African and Coloureds had the landmark measurements that changed most (page 119).

Prosthion was significant in most cases when correlated with body fat percentage, except when subdivided by sex, the increase was slightly negative (refer to Graph 4.16, page 91). The buccal region is an area of the face which undergoes atrophy or volume loss, while the cheek, lip and chin regions and the fat compartments of the lower face undergo hypertrophy with age (Donofrio 2000). The facial fat compartments are separate structures but many overlay each other. As one changes, it pulls on those surrounding it and leads to changes in the contours of the face

(Rohrich & Pessa, 2007). It is possible that increasing fatness of the face could alter the facial contours resulting in the decrease in the soft tissue thickness of Prosthion.

The coefficients of variation showed that females had a greater amount of variance compared to males, except for when White males were compared to White females. The T-tests and sequential Bonferroni method results showed that there were some greater differences between the soft tissue thicknesses of the sexes around the upper nose and mouth regions (page 138). However, this was not the case within the ancestry groups where the cranium and nose showed some greater variation.

The only landmarks at which there was some significant variation between the sexes, were Nasion and Vertex for all males and females, and Rhinion in the White ancestry group (page 150).

There was more variation between the BMI groups and the landmarks measurements of higher BMI individuals generally had a greater degree of variation, particularly in females. The degree of variation was higher when subdivided by ancestry group, particularly within the White participant groups.

In this study, there were two factors in which the differences in BMI influenced variation of the soft tissue depths: when the low and high BMI groups were compared, irrespective of sex or ancestry group, and when compared for females there was some variation at the facial widths, Gnathion and Maximum Occipital Point (page 151).

There were some landmarks at which the variances of the soft tissue depths when comparing high and low body fat percentages had some significance. The only factor for which this was not the case was when comparing the measurements of low and high body fat percentage were the White participants (Pages 146 and 152). The amount of variation of the landmark measurements tended to be higher in the high body fat percentage group, while the reverse was true for the Black African and Coloured ancestry group.

The changes in the soft tissue thicknesses in the lateral and chin regions of the face from participants of low and high body fat percentages showed greater variances. Body fat percentage appears not to influence the variances in the White ancestry group (page 152). Zygion and Gonion were also two of the landmarks that experienced the greatest change due to change in fatness. This indicates that there is a trend for a higher amount of soft tissue thickness variation as fatness increases, particularly along the facial widths.

It is possible that the sample size was the cause of the high degree of variation in some cases and must be remembered when considering the results.

This study showed that the regions of the chin and cheeks, the lateral width landmarks, show some changes with increased body fat percentage and BMI. This was the case for both sexes as well as the ancestry groups. Gonion was the landmark most greatly influenced, overall, for body fat percentage and BMI, followed by Zygion, Gnathion and Pogonion (Section 4.4. REGRESSION ANALYSIS OF TOTAL SAMPLE, page 86).

Few landmarks which had some significant changes as fatness increased differed between the sexes. More landmarks differed between the ancestry groups. When the influence of fatness on the ancestry groups and sexes is compared, body fat percentage is less influential on the ancestry groups (Section 4.4.4. REGRESSION ANALYSIS BY ANCESTRY GROUP, page 117). It has a greater influence on sex (Section 4.4.3. REGRESSION ANALYSIS BY SEX, page 97).

Outliers were noted and one male was a clear outlier in multiple analyses. The male did have the greatest height and weight measurements out of all participants, though not the greatest body fat percentage, indicating that weight does not necessarily indicate the degree of fatness. Another two participants with multiple outliers were females, one who did not possess any of the greatest measurements for height, weight, BMI or body fat percentage; and the other who only had the greatest BMI but fewer of the greatest measurements of the soft tissues of the landmarks compared to the other two participants.

The fact that they did not consistently have outlying measurements or greatest measurements shows that the relationship between soft tissue thickness and fatness is variable.

5.2. DOES IMAGE DISTORTION IMPACT ON THE ASSESSMENT OF FACIAL FATNESS?

Distortion found in LODOX® images does raise the question of how LODOX® images compare to other radiographic images and the measurements. This study included and initial phase where measurements were taken of the soft tissues of cadaver heads and then those same measurements were taken from radiographic images if the same heads. This was done to test whether LODOX® images were comparable to real physical measurements. They were found to be equivalent to measurements taken from LODOX® images of the same cadaver heads. This is consistent with other reports.

Smith and Throckmorton (2006) compared measurements from radiographs and ultrasounds. They found that the measurements from the radiographs were greater than those from the ultrasound, in the mid-plane, upper lip and nose. However, they noted that boundaries in ultrasound could be ‘fuzzy’ and that in cases where features over lap or the left and right sides are superimposed, indented landmarks may be difficult to pinpoint. It is possible that factors influencing soft tissue thickness at the time the different imaging methods were performed could have affected the results,

such as temperature, hormonal changes. While the differences may not be practically significant they do demonstrate that different data collection methods can produce different results.

The images from the LODOX® Statscan were comparable to regular X-rays, according to Beningfield *et al.* (2003), and no significant differences between physical and digital measurements was found in the initial phase of this study. Tabbara *et al.* (2011) noted that the quality of the images produced was comparable to conventional radiographs. The Stull *et al.* (2013) study found that measurements taken from LODOX® images were equivalent to those from actual bone (accepting the 2mm standard error generally accepted), though they did caution that soft tissue may present with greater distortion (Stull *et al.* 2013).

In answer to the question, no, image distortion from LODOX® images did not impact the soft tissue measurements.

5.3. IS FACIAL FATNESS BEST CORRELATED WITH BODY FAT PERCENTAGE OR BMI?

In this study two measures of fatness were used, BMI and body fat percentage. From the results it is clear that BMI more than body fat percentage affected the soft tissue thickness measurements of the face, BMI tracking with more significant changes. It is probable that because BMI measures not only fat but the other tissues that make up the body, that it would also account for other factors such as body build and density. What other variation or factors could account for this? And how may they influence the reconstruction process?

5.3.1. HOW DO MUSCULAR FEATURES IMPACT ON FACIAL SHAPE?

The facial muscles are a reflection of the general musculature of the body, which is reflected in the BMI measurements. The majority of facial 'bulk' and shapes is due to the facial muscles but predicting them is difficult, the soft tissue is an intricate and complex structure which is difficult to predict simply from the skull, and not all muscles are attached to the skull but to other soft tissues, such as the risorius and orbicularis oris muscles. This makes the determination of the muscle attachments subjective. Muscles can be highly variable in structure and presence too. The placement of the facial muscles is made even more subjective by their boundaries.

Of the 42 facial muscles only two have well determined boundaries on the skull which are predictable (Stephan 2003). This raises the question of how do we determine the muscle boundaries? In this study, the presence and appearance of the individual's muscles could not be ascertained and their affect on the soft tissue thicknesses remains unknown.

Can we identify specific muscles underlying the general anatomical structures in facial reconstruction and how? Currently, there are general guideline correlations for the shape and size of the muscles but they rely heavily on the subjectivity of the reconstruction practitioner (Stephan 2003). They often require artistic interpretation and the choice between two or more guidelines for approximating facial features, without knowing the error of the guideline (Stephan & Henneberg 2001; Stephan 2003).

Similarly, if the attachment size is considered ‘robust’ then the muscle is thought to be larger. However, this does not aid in determining where the muscle boundaries are, its precise weight, shape or exactly how large a ‘robust’ muscle is (Stephan 2003). More precise correlations are needed of these sites to determine the specific shape and size of each specific muscle.

5.3.2. HOW VARIABLE ARE FACIAL FATNESS DATA AND DOES BMI EXPLAIN THE VARIABILITY?

The relationship between the bone, soft tissue and facial morphology as represented in facial reconstruction is reliant on the expertise of the practitioner (Decker *et al.* 2013) and standardised data sets for tissue thicknesses which are normally grouped as emaciated, normal and obese (Gatliff 1984; De Greef *et al.* 2006).

Most reconstructions assume that the target individual falls into the ‘normal’ range of body fatness and, as facial fatness cannot be estimated from the skull (Wilkinson 2010), we cannot rely on such an assumption. Soft tissue thickness data sets concentrate on averages for population groups and not the full range of inter-individual variation. The use of radiographs from radiographic databases to determine soft tissue thicknesses from living individuals often means that the relevant information on body weight was not available (Cavanagh 2010; Cavanagh & Steyn 2011). In other cases, individuals who were considered to not be of a ‘normal’ body weight have been actively excluded from the study (Aulsebrook *et al.* 1996; Kurkcuoglu *et al.* 2011).

Yet, even in this study where there was no selection for body build or weight, nearly half the sample had a BMI< 25, and 28% had a body fat percentage indicating they were overweight or obese. South Africa is following the global trend towards higher levels of obesity with a progressive increase in obesity over the last few decades, with the increasing urbanisation of the population (Merwe & Pepper, 2006). The data for the South African adult population show increasing levels of overnutrition with the highest levels of obesity found in White males and African and Coloured females (Puoane et al, 2002).

Morris (2011) describes how during a routine class weighing exercise that he has not noticed an increase in BMI among medical students, the population sampled in this study, but that South Africa has become one of the top countries with a high level of overweight and obese people. As the University of Cape Town chooses its students by demographics, to represent the true population demographics of South Africa, this sample indicates that a 'normal' BMI is not the average for a South African sample, and that even if BMI is able to be estimated, it does not necessarily indicate body fat percentage.

We must then conclude that underweight and overweight individuals were included in the analysis of these other studies but their influence on the range of variation is not known.

The De Greef *et al.* (2006) study used ultrasound to look at soft tissue thicknesses of 967 whites and their relationship to BMI. They found that BMI had a greater impact on the soft tissue measurements of males than females, but that, irrespective of sex, some of the measurements had no correlation with age or BMI. Certain areas of the face, the mandible and maxilla, were more variable with changes in BMI, which showed that different body builds and weight do have an effect on the soft tissue thicknesses of the face. The measurements of those of White ancestry in this study were also found to be most affected by BMI in the chin and jaw regions, however the variation was not significant for either measure of fatness. The wide range of variation of the measurements further demonstrated the range of variation between individuals (De Greef *et al.* 2006).

Like in this study, Cavanagh and Steyn (2011) found that the landmarks with higher values occurred on the mouth and cheeks regions of the face and were the regions which were most variable with changes in fatness.

The Dong *et al.* (2012) study used CT scans of males and females of known BMI from Northern China. They defined the BMI categories as slender (BMI< 20), normal (20< BMI< 25) and obese (BMI> 25). They found that males had overall greater tissue thicknesses than females over any BMI category, but the range increased with higher BMI. As well, females had greater tissue thicknesses than males at different facial regions depending on their BMI category- as slender became obese, the higher measurements shifted from the upper to the lower face. This is different compared to this study where BMI did influence both sexes similarly, and that as BMI increased the regions most affected did not change.

However, only a third of the differences in the Dong *et al.* (2012) study between the sexes were found to be statistically significant, though there were different significant differences between the sexes for each of the BMI categories. There were significant differences in the midline landmarks of slender individuals, the lower third of the face in normal individuals, but only at two landmarks in obese individuals (Dong *et al.* 2012). Their study suggested that weight or fatness will impact soft tissue thicknesses differently for different levels of fatness, influencing the soft tissues in different facial regions.

In this study, the regions significantly affected by changing fat were the facial widths, with significant variation in the same regions. The facial widths did not change or vary to a significant degree much, only the landmark measurements of the brow of Black African and Coloured individuals varied to a significant degree. The Dong *et al.* (2012) study used a Northern Chinese sample and this one a South African, Black African, Coloured and White sample, which might account for the differences between their study and this one.

When the different databases for soft tissue thicknesses are compared, there are significant differences found between the landmark measurements (De Greef *et al.* 200 ; avanagh & Steyn 2011). The uy omarc'h *et al.* (2013) study compared 7 data sets and found that the factor which had the greatest influence on soft tissue thicknesses and exhibited the greatest variation between the different data sets was fatness (their estimated BMI or face build). Similarly, in this study, body fat percentage did influence the facial widths to a large degree but it was BMI which affected the majority of the landmark measurements and had the greater influence.

Body fat percentage is a measure of one of the tissues which occurs in the face and while increasing facial fat will lead to a fatter face, a fatter face will not necessarily mean greater body fat percentage. In comparison, BMI is a reflection of multiple factors including fatty tissue, muscle tissue, hydration and weight. If BMI is a better predictor of soft tissue thickness than body fat percentage, it is likely because it reflects overall body build and not just fatness.

5.4. HOW DOES DIFFERENT BIOLOGICAL ANCESTRY IMPACT ON FACIAL FATNESS?

Most data sets and studies emphasize subdivision of the data by these factors as surely they will have individualising affects on the soft tissues and, therefore, the face. However, are the differences reported between the various groups significant enough as to be of use or are they negligible? Is subdivision by biological factors justified (Stephan and Simpson 2005)? In this study the landmarks most influenced by changing fatness were the same for either sex or ancestry group, even examination of the variation showed little significant differences between the different groups.

In this study body fat percentage had less of an impact on the landmark measurements of the Whites, though the amount of change was similar. However, the areas that did change significantly with changes in body fat in Black African and Coloureds indicated that the tissues of the cranium increased as body fat increased.

The regions with the highest degree of variation in the Black African and Coloured ancestry were the facial widths, cranium, nose and lips. For Whites, the chin and lower lip regions were more varied. This is of interest as differences in the cheek, jaw and cranial regions of the skull are often examined to estimate ancestry. The nose and lips are two of the central features of the face which are very difficult to predict from the skull, and this indicates that as fatness increases that these features become even less predictable.

Stephan and Simpson (2008) found that the affects of ancestry on soft tissue depths was relatively weak, with the data showing broad but similar measurements. This was similar to the results of this study, where, except for na thion, the area’s most strongly affected by changing fatness were the same for both ancestry groups. Any differences likely resulted from the different measuring techniques used (şcan & Steyn 2013).

Similar to this study, u yomarc'h *et al.* (2013) found similar results between different ancestry groups and that the groups with the most similar results to their own were the South Africans of the study by Cavanagh and Steyn (2011). The two populations, French and South African, are geographically distant though the White South African population consists of largely European ancestry. The soft tissue thickness measurements indicate that population specificity is in fact lower than expected, but this could also be the result of a similar genetic history.

The Cavanagh and Steyn (2011) study found that their sample possessed more prominent and prognathic lips even as the data shows that lip thickness occurs more on the alveoli and not the teeth. Their sample was of South African Black females, who were included in this study which found that the mouth was one of the more variable regions of the face.

The Lebedinskaya and Veselovskaya (1993) study found a high degree of similarity between the soft tissues of the various Asian ancestry groups they studied. While they did find increases in the soft tissue thicknesses of the nasal region of their more European (or White) ancestry groups, this was not the case in this study. Instead, what was noted was a significant difference in the variation of the measurements of Nasion in Black Africans and Coloureds for low and high body fat percentages.

5.5. HOW DO SEX AND AGE IMPACT ON THE PATTERNS OF FACIAL FATNESS?

In this study the majority of participants were between the ages of 20 and 30 years old, while the oldest individual was 50. While age could not be analysed as a factor in this study, age is linked to fat patterning as an individual's fatness increases as they age (Gallagher *et al.* 1970). Similarly, females tend to have more body fat than males (Hattori *et al.* 1991; Sloan 1970). Though age is a factor that must be considered in estimating fatness, only accounting for a small amount of the variation in fat patterning, its influence does increase when sex is considered (Mueller *et al.* 1986). This suggests that both factors of sex and age interact to determine overall fat patterning, as age increases.

In this study, females had the highest body fat percentages, compared to males, despite the similar BMI levels between the sexes. Other studies have found that females tend to have larger fat deposits than males (Smalley *et al.* 1990; Gallagher *et al.* 1996; Luke *et al.* 1997). Fatness appeared to affect the landmark measurements similarly for males and females. The changes were larger in males compared to females, particularly around the lower jaw however, overall the regions where those changes occurred were similar, though the variation of the soft tissue measurements was greater in males than females when fatness levels were compared.

In this study, while Rhinion is in close proximity to Nasion, Glabella and Ophryon, landmarks that were significant in females, Rhinion was not significant in males. This area, the brow, is also an area often examined during sex estimation as an osteological feature that is more pronounced in males. The females in this study had larger brow soft tissue thicknesses than the males, which increased more rapidly as fatness increases, compared to males.

This was similar to De Greef *et al.* (2009) who found that the soft tissue differences of the brow were negligible, but like this study was larger in females. They suggested that age and sex have less influence on the soft tissue thicknesses than BMI, which follows with what was seen in this study, where sex and ancestry were similarly influenced by fatness.

They (De Greef *et al.* 2009) also noted that the mouth had the greatest soft tissue thickness changes due to age. This was in contrast to this study where despite age tending to affect similar regions of the face as in this study, the landmark measurements of the mouth region were not heavily affected by changing fatness.

Similar to this study, Cavanagh and Steyn (2011) also found the landmarks with higher values occurred on the mandible and maxilla (the mouth and cheeks) and were areas which were most variable with changes in body weight.

In comparison, the Dong *et al.* (2012) study sampled individuals of Northern Chinese ancestry, and did agree with Wilkinson (2004 reported in Iscan and Steyn 2013) that males had greater overall tissue thicknesses irrespective of fatness. Of interest was that that at different levels of fatness, different regions of the face were affected. This contrasts with this study where the same areas were affected by changing fatness. This might be due to the different ancestry groups of the two studies, Northern Chinese and South African.

This study agreed with uy omarc'h *et al.* (2013), that sex and fatness had a greater impact on the soft tissues than did ancestry. The differences between the sexes for their study were low, similar to this study, and they noted that males of greater

fatness tended to have greater soft tissue measurements. In this study the largest measurements tended to also be from a male with the greatest weight and height, and the second highest BMI.

The jaw, labiomental and nasolabial regions of the face increase in volume due to hypertrophy as the face ages (Donofrio 2000). These are also the areas in this study most affected by changes in fatness, particularly those areas around the jaw. The areas not seen to be heavily influenced by changing fatness in the study were also facial regions which undergo hypertrophy during aging. A fatter face will have greater fat compartments, thereby undergoing more change as fatness increases, due to weight gain or hypertrophy due to aging, changing the facial contours.

As Donofrio (2000, pp 1-6) describes it, “the morphological changes in the face at each stage of life are a result of fat distribution … facial aging is a complex synergy of surface textural and elastic changes, relative muscular hyperactivity and fat dimorphism”.

5.6. DRAWBACKS AND PROBLEMS TO CONSIDER

5.6.1. DIFFICULTY IN ATTAINING VOLUNTEERS

Volunteers were recruited from the student population of the faculty of Health Sciences of the University of Cape Town. It should be noted that there was a good deal of interest from the students in participating in this study. However, time constraints on the volunteers and access to the LODOX® Statscan severely limited the number of participants who could take part in this study.

Among the male participants there was some concern about the radiation effects of X-rays, particularly its effect on their fertility. Despite discussion and assurances about the low dose radiation of the LODOX® Statscan and being told how only the head would be scanned, many were still hesitant. The same concern was not raised by the female participants.

5.6.2. SUPINE POSITION DURING X-RAY

To produce a LODOX® Statscan image, the participant must be in a supine position for the free movement of the C-arm. A supine position can change how gravity affects the soft tissues of the face, especially the neck, mouth and cheek regions. Movement of the soft tissues of the cheeks can also deform the soft tissues in the eye region. Only the nose is relatively unaffected by position-related gravity changes (Tilotta *et al.* 2009). The supine position of most radiographic methods can often produce lower values in the facial midline but increase value in the bilateral landmarks, due to the effects of gravity on the soft tissues (Stephan & Simpson 2008).

Tilotta *et al.* (2009) compared results of their study with other studies taken in different positions and showed only minor differences in the soft tissue thickness measurements (Tilotta *et al.* 2009). However, other studies have shown that positioning may have no impact on the soft tissue thicknesses (Kim *et al.* 2005).

5.6.3. IMPLICATIONS OF SAMPLE SIZE

A total of 67 participants took part in this study and it is acknowledged to be a small sample size from which to gage the results. The effect of this small size is made more apparent when the data are divided by variables of sex, BMI, and ancestry group.

When testing whether there is a difference between two populations, the chance of a significant difference between two samples is 0.05. With a small sample any chance of finding that difference is also small. So, with small samples, any differences which are significant are more likely to be poor than with large samples (Bland 2008) and should be treated with caution.

The small sample size also limited subdivision of the data so that combined sex and ancestry group comparisons could not be performed and would have been meaningless as the sample size would have been too small. This also meant that any extremes in the sample (such as the maximum ages and weights) were included in the analysis and potentially impacted on the results.

Performing a power calculation to determine a desired sample size for this study was not possible as the sample relied on volunteers, a number which could not be guaranteed.

5.6.4. DIFFICULTY IN STANDARDIZATION AND USE OF LANDMARKS

The basis of any reconstruction is the facial landmarks used. While the face may remain the same, the landmarks lack standardization (Stephan & Simpson 2008; Cavanagh 2010). They can be difficult to interpret as different names and definitions are used (Stephan & Simpson 2008). Landmarks are more often described as a generalized region rather than as specific points, leading to variation in the exact point and potentially influencing the results of measurements and the placement of soft tissue depth markers (Cavanagh 2010). This makes repeatability and the comparison and use of different data sets difficult (Stephan & Simpson 2008).

In this study the landmarks (See chapter 3.2.1) were chosen largely for their visibility in the LODOX® images, using the definitions most agreed on in the literature and when an image of the landmark was present. There was some difficulty in determining the exact positioning of some landmarks, due to superimposition of the right and left features, as mentioned in Smith and Throckmorton (2006).

It is possible that difficulty in determining exact landmarks and their position could impact on the soft tissue depth data. Stephan and Simpson (2008) compared the data from multiple studies, focusing on the landmarks that could be more accurately assessed. They noted no clear trends at the most frequently used landmarks, despite a global increase in body mass. They pooled all published data in an attempt to overcome these differences in measurements and produced a generic soft tissue thickness value table (see figure 5.1) (Stephan & Simpson 2008; şcan & Steyn 2013).

The lack of standardization is slowly being improved on, and it must be acknowledged that each method of measuring the soft tissue thicknesses, imaging the soft tissues, approximating the face and even which data set is used has its pros and cons and contributes to the overall variation seen in the data and reconstructions (Cavanagh & Steyn 2011).

In this study intra- and inter-observer error could not be performed as reimaging and measuring of participants was not feasible and privacy limited measuring of the soft tissues from the LODOX® to the investigator only.

5.6.5. WHERE TO GO FROM HERE?

The results if this study showed that facial fatness did affect the soft tissue thicknesses of various landmarks of the face, particularly those on the lateral (cheeks and jaw) and inferior (chin) aspects or the widths.

Previous studies have shown that various radiographic means are capable of producing measurements analogous to those taken physically. Future studies should further research into the use of these means to obtain tissue depths from living people from which information on various factors; such as sex, population group and fatness, can be can be obtained. Age would be an important factor to account in the study of facial soft tissue thicknesses as well.

Extending the sample size is necessary to gain a greater understanding of which factors are the most variable and to what degree.

Studies on the distribution of body fat and BMI and their relationship to sex, ancestry and each other need further exploration, with particular attention paid to fat and its distribution in the face dependent on sex, ancestry and age.

Standardization of data gathering methods is important and each method has its advantages and disadvantages, and as of yet no method is known to be better than the others (Cavanagh & Steyn 2011). The De Greef *et al.* (2006) study indicated that a number of factors could contribute to the differences among the reported soft tissue thickness data of different studies, this included the variation in sample sizes, where many past studies had relatively small sample sizes; the use of cadavers, where post-mortem changes impact the soft tissues; and positioning of the subjects, where the supine position most commonly used can have gravity-related pull on the soft tissue.

6. CONCLUSION

It is known that fat influences tissue thicknesses in facial reconstruction. The results of this study showed that the facial width measurements, the soft tissue of the chin, jaw and cheek regions, are more affected by changes in facial fatness, than midline measurements. Of these regions the jaw, or landmark Gonion, was most strongly and consistently affected by changing body fat percentage and BMI, followed by Zygion, Gnathion and Pogonion.

Overall, increased body fat affected the areas most associated with age-related changes in the soft tissues, those areas that undergo hypertrophy of the fat compartments. Increased BMI will affect those areas first, then the nasal, brow and cranial regions. This was the case irrespective of sex or ancestry group.

Body fat percentage showed less of an influence on the soft tissue thicknesses compared to BMI, which appeared to be a better measure of soft tissue thickness. Variation tends to increase with increasing fatness, particularly around the facial features such as the mouth and nose, features already difficult to estimate in facial reconstruction. Females tended to have a greater amount of variation compared to males. Increasing body fat percentage tended to increase the amount of variation significantly in the facial widths, the same areas that underwent the greatest change as fatness increased.

Future studies should include larger sample sizes and populations of shared ancestry, to better describe the specific features which make a face recognisable.

Face morphology is a complex structure, the result of fat distribution, and therefore fat is an important factor in overall face appearance. General trends and guidelines are useful in approximating values for many reconstructions but they are limited in their variability. Instead, it would be better to use soft tissue thicknesses guidelines which are tailored to the individual.

Using sex and ancestry group specific facial tissue thickness data may not be appropriate as the influence of weight and fatness is similar across the sexes and ancestry groups. The variation in the soft tissue measurements in this study showed that while fatness is a factor in estimating soft tissue thickness and its variation, using sex and ancestry specific data sets may not be as important and understanding how and where the soft tissues vary as fatness changes.

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APPENDIX A: VOLUNTEER INFORMATION AND CONSENT FORM

Dear Participant,

You have volunteered to participate in this study by being X-rayed by LODOX® statscan and have body measurements taken. This study is for the completion of a Master's Degree in Applied Anatomy and will help us to develop more correct methods for facial reconstruction in forensic cases by giving us critical information that will help us understand how variation in soft-tissue thickness affects the accuracy of these reconstructions. Current methods do not give a true reflection of the individual because they ignore the variation in fatness.

You will receive a Participant Data Number and a card on which your information will be recorded. You will be asked to indicate your sex, age, and genetic population group. The genetic population groups are those used for Census 2011 and are requested as many studies have focused on the differences in facial tissue thicknesses between groups and one of the studies aims is to determine if genetic population group does in fact exceed the variation caused by body fatness.

Your height and weight will be measured and used to calculate BMI. Skinfold thickness measurements will be taken using the 4 site system of Durnin and Womersley (1974), the simplest method for doing so. This method was chosen as the least invasive means of measuring skin folds. The sites that will be measured are the subscapula, triceps, biceps and suprailiac.

LODOX® refers to low-dose x-ray, where the radiation is significantly lower, less than 25%, than for a normal X-ray. The length of exposure for a LODOX® image is 13 seconds for a full body scan. With the need to only image the head, the exposure time is even further decreased. The LODOX® image does not use film but is fed directly to computer where measurements of the soft tissues of the face will be will be done using the computer software.

By signing this declaration you are acknowledging the following:

- Your participation is fully voluntary
- All information will be kept anonymous and not be used for other purposes outside of this study
- You will have 2 LODOX® X-rays taken
- The following information will be requested from you: sex; age; height; weight; skin fold thicknesses of your triceps, biceps, subscapular and suprailiac; and ancestry.

Please note that you may opt-out at any stage and your data will be removed from the study.
Please contact the Faculty of Health Sciences Human Research Ethics Admin Office if you have any complaints or questions about your rights and welfare as participants.

I ....(articipant's name),

consent to participation in this study.

Data u mber:……………………..

Signature:.......................................

Date:..

Females: Regarding Possibility of Pregnancy: This is to certify that, to the best of my knowledge, I am not pregnant, and I give my permission to perform LODOX® imaging.

Signature:.......................................

Date:..

Researcher Signature:………………………….

Date:……………………………………………

Researcher Contact Details:

Email: carrie.clarke@uct.ac.za

Phone: 072 997 5545

FHS Human Research Ethics Admin Office

Chair: Prof Marc Blockman

Human Research Ethics Committee

E 52, Room 24, Old Main Building, Groote
Schuur Hospital, Observatory

Telephone: 27 21 406 6338

Fax: 27 21 406 6411

APPENDIX B: VOLUNTEER DATA CARD

Volunteer Data Card

No: ______________________________

Sex (circle): M F

Age:________

Please circle your Genetic Population Group as defined by Statistics South Africa: Census 2011: Black African; Coloured; Indian/Asian; White; Other

Height:_____________ Weight:_____________

BMI:_____________

Volunteer Data Card

Skin fold thickness measurements:

	1	2	3	Average
Biceps				
Triceps				
Subscapular				
Suprailiac				

Body fat % _______________

APPENDIX C: DATA

ID	Sex	Age	Ancestry	Height	Weight	BMI	Biceps	Triceps	Subscapular	Supra-iliac	Body Fat Percentage
1	F	21	W	161.90	51.90	19.80	12.20	17.70	11.00	12.30	27.73
2	F	22	W	165.60	54.30	19.80	8.00	17.60	11.70	9.60	25.93
3	F	26	W	161.10	63.80	24.60	12.30	14.70	14.80	10.60	27.51
4	F	26	W	164.60	76.20	28.10	12.30	18.80	18.60	17.30	31.06
5	F	24	W	149.50	77.20	34.50	22.00	20.70	43.20	17.20	37.42
6	F	29	W	163.10	68.70	25.83	9.00	31.10	22.50	21.83	34.45
7	F	26	W	169.40	65.30	22.76	6.73	15.33	8.83	22.67	27.83
8	M	23	W	184.00	69.70	20.59	2.83	5.10	9.07	5.83	9.51
9	M	22	W	177.50	71.60	22.73	4.83	13.00	10.76	6.50	14.59
10	F	27	W	168.00	83.10	29.44	15.62	30.63	18.67	13.67	33.40
11	F	25	IA	155.20	56.10	23.29	8.00	26.77	16.50	15.83	31.08
12	F	23	W	163.80	66.40	24.75	5.43	34.00	15.17	17.00	32.03
13	F	24	W	169.00	55.50	19.43	5.83	16.90	7.93	14.73	25.46
14	F	25	W	159.95	54.80	21.42	11.17	27.00	10.67	2.00	27.08
15	M	23	C	168.90	69.50	24.36	5.20	16.17	16.93	20.20	20.79
16	F	23	W	161.30	71.80	27.60	14.87	25.53	22.40	14.00	33.06
17	F	25	C	158.50	44.30	17.63	2.60	12.33	8.73	7.17	20.02
18	F	23	W	171.90	77.30	26.16	14.27	35.44	15.50	18.33	34.30
19	F	24	BA	152.00	58.10	25.15	4.17	24.67	14.17	15.33	29.05
20	M	24	W	179.00	76.70	23.94	2.67	11.17	14.57	12.67	16.48
21	M	24	BA	184.30	85.90	25.29	7.00	33.50	15.00	24.00	24.59
22	M	45	BA	177.30	75.60	24.05	4.60	21.83	14.50	18.26	26.90
23	F	22	BA	172.30	53.50	18.02	3.40	13.60	5.83	7.83	19.95
24	F	20	W	172.60	77.40	25.98	9.90	23.30	10.16	7.30	27.03
25	F	19	W	179.60	66.20	20.52	4.50	14.30	8.83	4.16	20.07
26	M	21	BA	169.30	65.40	22.82	2.50	4.60	5.83	6.83	7.82
27	M	21	BA	171.80	69.90	23.68	3.10	5.00	11.16	8.00	11.59
28	F	27	BA	164.10	52.30	19.42	6.30	19.00	9.30	7.16	24.28
29	F	22	C	159.60	49.30	19.35	5.53	18.93	14.56	9.93	26.54
30	F	19	W	164.10	49.60	18.42	8.93	16.93	10.73	6.23	24.01
31	M	21	W	171.30	65.20	22.22	2.46	14.73	8.30	12.76	15.63
32	F	20	C	173.40	82.80	27.54	6.56	30.60	12.56	15.06	30.57
33	F	19	BA	159.60	87.30	34.27	16.80	36.48	23.96	32.06	36.88
35	F	41	C	179.00	87.00	27.15	8.20	30.23	21.06	27.30	37.85
36	F	20	BA	173.40	112.80	37.52	20.00	46.00	22.80	14.60	37.46
37	F	20	BA	148.90	58.70	26.48	7.90	22.50	12.10	14.06	28.61
39	M	25	W	185.60	141.80	41.16	16.43	22.23	32.10	33.90	28.05
40	F	20	IA	164.80	60.60	22.31	6.87	18.20	10.70	11.67	26.09
42	F	20		168.40	66.90	23.59	7.83	18.60	11.27	13.00	27.04
43	F	19	C	165.60	77.50	28.26	12.23	23.57	13.73	14.50	29.45
45	M	21	BA	170.00	70.20	24.29	5.17	13.80	13.10	14.20	17.93

46	M	19	BA	177.90	89.70	28.34	6.40	24.27	20.67	13.60	22.41
47	F	19	BA	148.70	68.20	30.84	10.47	22.03	13.30	16.93	29.17
48	M	19	C	170.00	78.60	27.20	2.80	7.93	17.00	14.80	17.25
49	M	20	BA	160.20	52.30	20.38	2.70	11.40	13.47	5.93	14.04
52	F	20	BA	161.50	81.50	31.25	15.07	28.97	30.23	24.13	36.72
54	F	18	BA	154.85	52.40	21.85	5.23	26.73	16.40	12.90	28.85
55	F	19	BA	159.00	51.30	20.29	4.10	14.00	6.40	7.50	20.15
57	F	19	BA	169.60	64.20	22.32	5.00	14.53	13.40	5.93	22.72
58	F	19	C	171.10	55.70	19.03	7.10	12.07	8.50	11.13	22.70
59	F	22	W	168.90	64.70	22.68	30.50	24.83	14.93	17.30	34.99
60	F	23	W	161.60	93.30	35.73	21.30	45.53	19.90	11.83	36.75
61	M	28	C	173.00	101.40	33.88	11.73	14.20	21.13	23.83	23.17
62	M	24	BA	174.70	77.80	25.49	4.97	7.87	15.30	20.47	18.53
63	M	25	BA	165.00	59.40	21.82	2.57	10.07	9.33	7.47	12.50
64	F	23	W	165.30	57.00	20.86	16.57	6.17	7.97	12.83	24.87
65	F	22	C	166.60	88.40	31.85	14.67	32.50	21.97	21.73	35.54
66	F	23	O	166.50	73.40	26.48	9.97	22.27	17.57	15.90	30.78
68	F	22	W	161.70	91.60	35.03	19.73	36.07	22.03	21.90	36.93
69	F	19		159.70	107.10	41.99	20.67	37.07	11.83	24.13	34.72
70	F	50	W	154.70	71.60	29.92	16.80	26.07	21.77	22.23	40.66
71	F	19	C	163.80	57.80	21.54	4.87	19.57	14.23	15.97	27.29
72	F	20	W	153.60	50.40	21.36	5.80	16.13	10.57	10.10	24.56
74	F	20	W	163.00	57.60	21.68	7.90	18.80	9.53	18.70	28.19
75	F	20	BA	161.00	52.00	20.06	6.13	24.43	8.07	14.33	27.67
76	F	30	BA	162.00	60.40	23.01	10.43	29.17	15.20	23.80	34.10
77	F	24	W	177.00	53.90	17.20	5.07	15.23	14.40	14.20	26.52

ID	Nasion	Glabella	Ophryon	Gnathion	Pogonion	Supra-mentale	Inion	Mid-lip	Prosthion	Mid-philtrum	Nasal Tip	Rhinion	Maximum Occipital Point	Vertex	Gonion	Zygion	Euryon
1	0.72	0.69	0.57	0.87	0.82	1.24	0.94	0.22	1.45	1.58	2.94	0.15	0.56	0.42	0.91	0.97	0.53
2	0.72	0.62	0.56	0.77	1.05	1.18	1.02	0.61	1.60	1.44	3.04	0.24	0.77	0.67	1.22	1.00	0.90
3	0.89	0.71	0.60	0.78	1.18	1.57	1.25	0.76	1.36	1.76	3.10	0.22	1.06	0.76	1.17	1.10	1.00
4	1.04	0.73	0.65	0.48	0.76	1.05	0.88	0.61	1.21	1.60	3.26	0.16	0.65	0.53	1.23	0.84	0.89
5	0.92	0.70	0.62	1.11	1.29	1.63	1.20	0.57	1.15	1.52	2.58	0.30	0.69	0.50	2.10	1.15	0.62
6	0.88	0.80	0.78	0.91	1.12	1.42	0.98	0.62	1.39	1.69	3.14	0.31	0.68	0.55	2.65	1.42	1.35
7	0.86	0.73	0.65	0.74	0.79	1.51	1.14	0.46	1.29	1.63	2.95	0.32	0.92	0.70	1.80	1.48	1.10
8	0.99	0.72	0.70	1.09	0.80	1.59	1.32	0.98	2.22	2.20	3.80	0.29	0.92	0.68	1.15	0.80	1.06
9	1.06	0.77	0.87	0.92	1.07	1.60	1.19	0.83	1.69	2.45	3.30	0.56	0.95	0.65	1.36	1.01	1.18
10	0.87	0.64	0.73	2.06	0.98	1.78	1.14	0.33	1.73	1.69	3.35	0.28	0.82	0.59	2.40	1.26	0.93
11	0.77	0.62	0.55	0.51	0.60	1.31	0.98	0.69	1.49	1.51	2.99	0.30	0.84	0.60	1.22	0.59	0.96
12	0.92	0.72	0.62	0.66	0.82	1.88	1.15	0.44	1.77	1.91	3.11	0.31	0.78	0.53	1.82	1.52	1.13
13	0.72	0.52	0.58	0.72	0.63	1.50	1.00	0.37	1.51	1.40	3.06	0.17	0.54	0.42	0.99	0.83	0.63
14	0.82	0.63	0.52	0.89	0.84	1.75	1.14	0.47	1.44	1.93	3.80	0.26	0.63	0.42	1.03	0.95	0.62
15	0.97	0.61	0.60	0.96	0.77	1.68	1.19	0.86	1.44	1.65	2.86	0.39	0.88	0.64	1.21	0.88	0.78
16	1.00	0.76	0.71	0.92	0.88	1.60	0.99	0.39	1.66	1.74	3.67	0.32	0.63	0.60	1.24	1.01	0.70
17	0.80	0.61	0.49	0.73	0.81	1.31	0.97	0.57	1.41	1.55	3.01	0.24	0.83	0.60	0.96	0.68	0.79
18	0.84	0.62	0.63	0.88	1.34	1.98	1.59	0.42	1.60	1.61	3.27	0.32	0.95	0.77	1.35	0.84	0.89
19	0.95	0.80	0.72	0.72	1.11	1.62	1.10	0.63	1.13	2.02	3.13	0.44	1.13	1.02	1.58	1.49	1.45
20	0.85	0.82	0.68	1.00	1.16	1.69	1.24	0.99	1.87	2.08	3.37	0.37	0.77	0.60	1.18	0.62	1.14

ID	Nasion	Glabella	Ophryon	Gnathion	Pogonion	Supra-mentale	Inion	Mid-lip	Prosthion	Mid-philtrum	Nasal Tip	Rhinion	Maximum Occipital Point	Vertex	Gonion	Zygion	Euryon
21	0.60	0.57	0.60	0.82	1.24	1.72	1.20	0.50	1.41	1.52	3.19	0.45	1.29	0.87	1.99	1.22	1.22
22	0.71	0.74	0.65	0.97	1.47	1.29	1.20	0.61	1.32	1.72	2.36	0.40	1.13	0.84	2.09	1.23	1.69
23	0.47	0.66	0.67	0.46	1.14	1.61	0.90	0.31	1.29	1.68	2.78	0.31	0.79	0.91	1.46	0.90	0.95
24	0.85	0.67	0.74	0.54	0.98	1.20	1.02	0.14	1.93	1.62	3.13	0.29	0.70	0.56	1.49	0.70	0.75
25	0.75	0.56	0.62	0.52	0.89	1.56	1.01	0.27	1.34	1.13	3.55	0.20	0.70	0.49	1.06	0.81	0.71
26	0.66	0.84	0.63	0.52	1.26	1.44	1.16	0.67	1.51	1.34	3.41	0.28	0.69	0.61	1.34	0.76	0.96
27	1.05	0.76	0.72	1.12	0.65	1.66	1.03	0.47	1.77	1.58	2.65	0.32	0.78	0.81	1.07	0.78	0.96
28	0.66	0.61	0.56	0.43	0.58	1.26	1.03	0.67	1.32	1.56	2.45	0.27	0.78	0.70	1.00	0.69	0.85
29	0.84	0.62	0.57	0.51	0.89	1.37	0.95	0.42	1.33	1.54	2.30	0.34	0.76	0.70	0.87	0.78	0.91
30	0.81	0.61	0.55	1.03	1.02	1.36	1.11	0.72	1.53	2.04	3.09	0.22	0.55	0.40	1.50	0.81	0.72
31	0.84	0.61	0.56	0.66	0.55	1.31	0.92	0.53	1.53	2.08	2.76	0.24	0.71	0.46	0.90	0.79	0.69
32	0.89	0.76	0.70	0.94	0.87	1.82	1.29	0.46	1.63	1.92	3.02	0.28	0.91	0.77	1.73	1.23	0.98
33	0.85	0.88	0.88	1.37	1.39	1.41	1.20	0.90	1.37	2.03	3.05	0.57	1.41	0.92	3.44	2.20	1.54
35	0.77	0.66	0.58	1.30	1.30	1.48	1.34	0.61	1.43	2.22	2.79	0.23	0.91	0.69	1.64	1.23	0.96
36	0.77	0.79	0.67	0.95	1.62	1.32	1.24	0.83	1.21	2.07	2.72	0.47	1.20	0.99	2.27	2.03	1.52
37	0.69	0.69	0.69	0.53	0.74	1.54	1.04	0.26	1.50	1.04	2.59	0.39	0.82	0.84	2.00	1.31	0.82
39	1.58	1.00	1.03	2.13	1.53	1.81	1.48	1.12	2.00	2.10	2.87	0.63	1.24	0.80	4.12	2.37	1.21
40	0.75	0.58	0.49	1.00	0.87	1.46	0.98	0.84	1.33	1.52	2.46	0.32	0.80	0.58	1.48	0.95	0.80

ID	Nasion	Glabella	Ophryon	Gnathion	Pogonion	Supra-mentale	Inion	Mid-lip	Prosthion	Mid-philtrum	Nasal Tip	Rhinion	Maximum Occipital Point	Vertex	Gonion	Zygion	Euryon
42	0.53	0.53	0.60	0.65	0.89	1.33	1.05	0.31	1.07	1.15	2.35	0.52	0.95	0.68	1.07	0.77	0.78
43	0.65	0.74	0.58	0.83	0.78	1.55	1.18	0.19	1.30	1.80	2.70	0.31	0.99	0.60	1.62	1.28	1.09
45	1.17	0.69	0.64	0.70	0.75	1.35	1.27	0.74	1.56	2.26	2.74	0.28	1.07	0.79	1.41	0.98	0.92
46	0.92	0.87	0.80	1.15	1.10	1.83	1.40	0.68	1.54	2.25	2.80	0.47	0.99	0.81	1.41	1.40	1.18
47	0.69	0.70	0.76	0.82	0.78	1.40	1.00	0.64	1.29	1.27	2.39	0.40	0.96	0.91	1.98	1.41	1.42
48	0.99	0.80	0.73	0.89	0.78	1.12	1.06	0.70	1.36	2.07	3.14	0.31	0.91	0.72	1.41	1.02	0.96
49	0.71	0.60	0.52	0.57	0.72	1.66	1.06	0.88	1.62	2.73	2.71	0.33	0.72	0.58	1.29	0.52	0.87
52	0.82	0.79	0.79	1.63	1.39	1.24	1.19	0.40	1.29	1.50	2.50	0.43	1.10	0.85	1.90	1.53	1.17
54	0.60	0.54	0.64	0.68	1.15	1.46	1.06	0.60	1.36	1.58	2.44	0.22	0.91	0.67	1.52	1.11	1.00
55	0.55	0.47	0.55	0.65	1.08	1.44	1.01	0.64	1.26	1.50	2.54	0.30	0.77	0.74	1.27	0.81	0.92
57	0.77	0.79	0.85	0.45	0.74	1.41	0.93	0.64	1.32	1.75	2.76	0.35	0.81	0.82	1.56	0.99	1.03
58	0.84	0.66	0.52	0.67	1.14	1.20	0.85	0.58	1.24	1.72	2.99	0.30	0.80	0.77	1.22	0.98	1.01
59	0.83	0.60	0.55	0.60	0.76	1.53	0.94	0.29	1.04	1.25	2.88	0.18	0.58	0.34	1.23	1.27	0.82
60	1.01	0.80	0.64	1.02	1.36	1.42	1.21	0.69	1.38	2.06	3.17	0.20	0.79	0.84	1.71	1.29	0.89
61	1.20	0.90	0.75	1.14	1.68	1.43	1.31	0.98	1.94	2.56	3.75	0.33	1.10	0.62	2.20	1.80	1.35
62	0.87	0.63	0.58	0.79	1.31	1.21	1.22	0.85	1.71	2.13	3.55	0.37	0.90	0.72	1.41	1.07	1.18
63	0.70	0.55	0.56	0.65	1.10	1.50	1.07	0.51	1.37	1.92	3.46	0.24	0.79	0.69	1.10	0.79	1.02
64	0.69	0.55	0.46	0.52	0.84	1.20	1.05	0.17	1.24	2.15	3.22	0.25	0.60	0.53	0.82	0.77	0.67
65	0.88	0.83	0.77	1.45	1.39	1.59	1.27	0.60	1.40	1.50	2.67	0.42	1.27	1.05	2.27	1.61	1.04

ID	Nasion	Glabella	Ophryon	Gnathion	Pogonion	Supra-mentale	Inion	Mid-lip	Prosthion	Mid-philtrum	Nasal Tip	Rhinion	Maximum Occipital Point	Vertex	Gonion	Zygion	Euryon
66	0.65	0.72	0.76	1.00	1.45	1.19	0.92	0.36	1.38	1.65	2.96	0.25	1.12	0.85	1.43	1.29	1.13
68	0.95	0.86	0.81	1.15	1.30	1.33	1.24	0.53	1.24	1.79	3.46	0.28	0.94	0.68	1.55	1.34	1.02
69	0.82	0.98	1.14	2.03	1.45	2.33	1.09	0.78	1.17	1.58	2.75	0.39	1.09	0.73	3.69	2.06	1.51
70	1.13	0.84	0.75	1.24	1.35	1.48	1.27	0.81	1.59	1.70	2.64	0.36	0.78	0.51	2.52	1.24	0.91
71	0.61	0.51	0.49	0.50	0.93	1.23	1.05	0.65	1.22	1.52	3.13	0.23	0.92	0.66	1.33	0.96	0.93
72	0.86	0.56	0.49	0.51	0.82	1.30	0.81	0.39	1.20	1.46	2.77	0.19	0.81	0.55	1.17	1.11	0.80
74	0.71	0.61	0.52	0.70	0.82	1.01	0.91	0.32	1.02	1.40	2.49	0.15	0.74	0.40	1.10	1.00	0.75
75	0.50	0.53	0.50	0.45	0.60	1.29	0.98	0.57	1.11	1.57	2.91	0.21	0.79	0.57	1.25	0.89	1.10
76	0.83	0.69	0.58	0.52	0.57	1.62	1.33	0.56	1.26	1.41	2.83	0.21	1.01	0.78	1.48	1.09	1.03
77	0.77	0.55	0.47	0.57	1.11	1.11	1.21	0.54	1.20	1.61	2.94	0.26	0.59	0.39	1.00	0.83	0.83