Towards a Unified Facial Tissue Thickness Model from Neuroimaging Data for Selected Age Groups of Sri Lankan Adult Population

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This dissertation is submitted to the University of Colombo School of Computing
In partial fulfillment of the requirements for the
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Declaration

I, W.U.A. Jayawardena, 2013/IS/025 hereby certify that this dissertation entitled 'Towards a Unified Facial Tissue Thickness Model from Neuroimaging Data for Selected Age Groups of Sri Lankan Adult Population' is entirely my own work and it has never been submitted nor is currently been submitted for any other degree.

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I, W.K.H. Sandamini, 2013/IS/047 hereby certify that this dissertation entitled 'Towards a Unified Facial Tissue Thickness Model from Neuroimaging Data for Selected Age Groups of Sri Lankan Adult Population' is entirely my own work and it has never been submitted nor is currently been submitted for any other degree.

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I, Damith D Karunaratne, certify that I supervised this dissertation entitled 'Towards a Unified Facial Tissue Thickness Model from Neuroimaging Data for Selected Age Groups of Sri Lankan Adult Population' conducted by W.U.A Jayawardena, W.K.H. Sandamini and B.L.Thathsaranee, in partial fulfillment of the requirements for the degree of Bachelor of Science Honours in Information Systems.

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Abstract

Facial soft tissue thickness (FSTT) is essential in forensic anthropology for facial reconstruction, recreating a recognizable face from an unidentified skull and plastic surgeons for treatment planning. Together with the age and sex of a person, the facial profile is related to facial soft tissue thickness, which is required for accurate facial reconstruction and recognition.

In this study facial soft tissue thickness was measured at 23 standard anthropological landmarks using Magnetic Resonance Images (MRI) of 243 adult individuals (male - 123, female - 120) of the Sri Lankan adult population which were collected as clinical data from the National Hospital of Sri Lanka. Inter observer variability of the measurements were measured and it was proved that the difference between measurements of the three observers were minimum. For each landmark, average thickness value, standard deviation, range, maximum and minimum facial soft tissue thickness values classified according to the gender and age were documented. Mean FSTT classified according to age and gender was then compared with age groups, gender groups and studies of three foreign countries selected. All the comparisons were done based on graphical visualizations and statistical methods. Statistical analysis and learning methods were used for missing FSTT value imputation individual cases.

From the comparison of FSTT within gender groups it was found that men have comparatively higher FSTT than women. The area along the midline of men always shows higher FSTT than female. The area around the cheeks (represented by Jugale, Zygomatic Arc and Supra Glenoid) also show comparatively large tissue thickness in young men (within 20-39 age range) than in women groups.

From the comparison of FSTT within age groups it was observed that the thickness at some landmarks decrease or increase with age while some do not show a specific formal pattern variation with aging. Also it was found that males have the highest FSTT at the age range of 40-49. In both males and females FSTTs at points like Midphiltrum and Upper Lip Margin gradually decrease with the age. In females the FSTTs at Supra Orbital, Jugale, Zygomatic arch and Supra Glenoid landmark increase with age. Males have the least FSTT mean for Supra Orbital, Jugale, Zygomatic arch and Supra glenoid landmarks at the age range 20-29, but it doesn't show a direct or inverse relationship between FSTT and age when other age ranges are considered.

With the comparison of three foreign studies (Taiwanese, Turkish and North West Indian) with the Sri Lankan study it was observed that Taiwanese population shows less

significant difference with compared to the Sri Lankan population. However due to the unavailability of raw data statistical interpolation of missing values using foreign data was not performed.

A part from statistical analysis learning methods were established towards estimating missing data values. A regression tree analysis was done for 40-49 and 50-59 age groups with the clustered components(which comprised of landmarks) using Principal Component Analysis and Factor Analysis methods. Hence the objective of interpolation of missing values towards making a unified facial tissue thickness model was achieved through this.

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Finally this thesis is also dedicated to our parents who have been an immense support to us throughout this journey. It is a great pleasure for us to acknowledge the assistance and contribution of all the people who helped us to successfully complete our research.

1. Chapter 1-Introduction

1.1. Introduction

With the occurrence of natural disaster like tsunami or terrorist bombings, a country will be bestowed with piles of unidentified dead bodies. In all such tragic events which results in skeletonized, decomposed or badly mutilated human bodies remain, it is of utmost importance to uncover the identity of the deceased due to a number of reasons. Forensic facial reconstruction (FFR) is the process by which facial approximations are generated by using the skeletal remains of the deceased.

Today the reconstruction of the face is done based on the skull via computer based 3D methods. Producing a face from the skull using FFR relies on a relationship between the soft tissues covering the skull. Prevalence of adequate data on facial soft tissue thickness (FSTT) for facial reconstruction would make it possible to reconstruct the face which looks much similar to the deceased person.

In addition to the above scenario we can identify many instances where the FSTT comes into action. During accidents, sometimes the faces of the people get injured badly and they have to be undergone with plastic surgeries to take the face back to normal. Before reconstructing or altering the face through a plastic surgery, it is necessary to determine the shape of the face. For that it is important to know the FSTT at particular defined landmarks.

In sculpturing also, for more accurate output it is advantageous to know the FSTT at certain landmarks. In such occasions, having a database with facial tissue thickness in the Sri Lankan context which can be used as a reference to get FSTT is very advantageous. Having a unique facial soft tissue thickness database for each population is important since the facial soft tissue thickness gets differ from population to population due to the factors such as weather, climate which result different facial soft tissue thicknesses [1].

1.2. Motivation

In the global context (especially in developed countries) studies have been conducted to establish FSTT measurements (database) for different population groups. Those studies have been targeted tissue thickness measurement through Ultrasound technology or Computed Tomography (CT) or Magnetic Resonance Imaging (MRI) techniques.

According to the literature developed countries possess unified Soft Tissue Thickness models for their own contexts. A unified model for a particular country means a unique model which is applicable for any age group of the country. Currently, tissue depth standards are available for several population groups including Native Americans [2], Koreans [3], Japanese [4], Chinese [5], South Africans [6], Canadians [7], Turkish [8] and Indian populations including Southwestern India [9],Gujarati [10] and North Western India[11] and Europe[12].

When we come to the Sri Lankan context, currently there is no repository in national level which contains tissue thickness values for Sri Lankan population (to the best of our knowledge literature does not indicate about any FSTT repository for the Sri Lankan context). Through the early stages of this research, the researchers have attempted to analyse the skin tissue thickness patterns pertaining to the Sri Lankan population of the 20-30 age category. That is the only study that has been done for the Sri Lankan context. This pilot study was conducted using CT images collected from Medical Institutions of Sri Lanka. However, many local medical officers have highlighted the national importance of a comprehensive set of data covering all age groups for Sri Lanka. As the next stage, through this research we hope to complete the medical database which was restricted to the age group 20-30.

As mentioned above many studies were conducted in the global context to establish soft tissue thickness (STT) models as a reference to get the facial tissue thickness values. In some of those instances researchers have collected MRI data specifically for their study purposes only, such data collections is not practical in Sri Lanka. As examples, in a study done at Czech Republic, the researchers used head CT scans of 102 adult Czech individuals between the ages of 21 and 83 to find any relation between facial soft tissue thickness (FSTT) and sex, age and asymmetry in the contemporary Czech population [13]. Also in a study done

at France, they investigated the variability of FSTD (Facial Soft Tissue Depth) collected at 37 landmarks on 500 CT scans of French living individuals [14]. But in Sri Lanka there is less possibility to collect MRI data specifically for this type of a study.

Therefore, we intend to collect MRI data captured for clinical purposes from medical institutes in the country. Here the main issue is that, as the data capturing is not under the purview of the project team, we have no control over the data Therefore, it is apparent that all the required data will not be able capture from the sample. This research aims to firstly, overcome this issue by using statistical analysis and learning methods to infer the missing data values. Secondly, once the data sets are established, we aim to assess the possibility building a unified facial tissue thickness model for Sri Lanka to be utilized in all the relevant fields.

1.3. Goals and Objectives

Objective 01- Complete the facial skin tissue thickness database consisting of all the records of the measured samples to cover 20-59 age category (20-29, 30-39, 40-49, 50-59)

Under the first objective we are to complete the medical database which was restricted to the 20-30 age category to reflect a wider age range.

The following table contains the minimum number of samples which have been collected for this project (Table 1.1). The age range and sample size were selected by analysing similar studies conducted by other countries in the literature (Table 2.2).

Category description	**Elements included in the category**	**Number included for each element**
The age range in consideration for the project	20- 59 years	4
Genders	Male & Female	2
Tissue thickness samples per category		16
Complete number of Samples		16x2x4 =128

Table 1.1: Tissue thickness sample size calculation

According to the aforementioned table the age ranges which are considered in this

research are 20-29, 30-39, 40-49 and 50-59. The sample size for each age category should consist minimum of 32 subjects consisting of 16 males and 16 females.
The age range and sample size were selected by analysing similar studies conducted by other countries in the literature [Table 2.2].

Objective 02- Constructing a unified facial tissue thickness model for selected age groups of Sri Lankan adult population

In the early stages of this project attempts were taken to analyse skin tissue thickness patterns pertaining to Sri Lankan population of the 20-30 age category [40]. However due to the unavailability of substantial number of samples, a statistical analysis was not conducted. From the whole set of samples gathered through this research our intention is to evaluate whether it is possible to find out the missing values through statistical interpolation and to evaluate whether a unified facial tissue thickness model could be generated for the Sri Lankan context.

Objective 03- Reconstruction of a new case (reconstruction of a face using the skull of a known victim) to validate the process for the new data

Assessing the accuracy of the created model before using it in the real world is very important. From the aforementioned objectives one and two, our next objectives is to reconstruct a new case with the data in the created database in order to validate model. The new case will be constructed based on a known skull (which we know who the owner is with an ante-mortem photograph of the owner).

1.4. Research Approach

The research approach is a quantitative approach of which an analysis of numerical data is done. In order to address the two questions stated, data sources for the data collection processes is neuro images. Those collected images were converted into the numerical figures in the data processing phase. Once the data is processed and numerical figures are gained for all age categories, first objective as mentioned above, complete the facial skin tissue thickness databases to cover all age categories aimed to be gained.

In the next phase, the processed data was prepared for statistical analysis. Once this is done, the possibility of generating a statistical model was evaluated. It was aimed to achieve

the second objective as mentioned above, constructing a unified tissue thickness model for Sri Lanka. In addition the statistical analysis permitted us to discover trends within Sri Lankans and thereby determine missing soft tissue thickness values of the Sri Lankans.

1.5. Delimitation

1.5.1. In Scope:

- As the initial step MRI data collection was done from medical institutes of Sri Lanka.
- The targeted data extraction is for,
    - Age Range: 20 to 59
    - Gender: Male and Female

  Individuals.
- Even data was collected and basic statistics was performed for all 20-59 age groups, the further analysis with learning methods was performed only with the 40-49 and 50-59 age groups where sufficient amount of data was present.
- After the sample template data sets are established, the image pre-processing was performed for the automated extraction (discovery) of the anthropometric landmarks on the MRI using MATLAB. Canny edge detection algorithm was used for this purpose. Further processing was done depending on the nature of the MRI images.
- Here we consider 23 anthropometric landmarks (as stated below) of the face of which some of them were used in the early stages of this research as well.

1. Bregma
2. Glabella
3. Nasion
4. End of Nasal bone
5. Mid-philtrum
6. Upper lip margin
7. Lower lip margin
8. Chin-lip fold
9. Mental eminence
10. Beneath Chin
11. Supra orbital
12. Infra orbitale
13. Ectoconchion
14. Inferior malar
15. Supra-Canine
16. Infra-Canine
17. Jugale
18. Zygomatic arch
19. Supra glenoid
20. Mastoidale
21. Euryon

22. Supra M2
23. Sub M2

- Then the FSTT measurements from the above stated landmarks were taken from Radiant DICOM viewer software.
- Processing of acquired raw data was done using statistical analysis methods from R x 64 bit 3.4.1 and IBM SPSS Statistics 20 software.
- Through statistical interpolation methods missing FSTT measurements were to be derived by comparing with foreign studies.
- A FSTT database was created using the whole set of values (excluding the derived ones)
- An evaluation was done to check whether a tissue thickness model (reconstructed face model) can be built from the data set.
- Ultimately, a new case (face of a deceased known person) is being reconstructed.

1.5.1. Out of Scope:

- Here we are analysing only the skin tissue thickness. The facial features like nose, eye and ears are not analysed under this research.
- When selecting the neuro images, samples without abnormalities (fractures, facial injuries) are only selected.
- Weight factor is not considered when collecting neuro images for each age category

2. Chapter 2-Background

2.1 Early Attempts of Measuring Facial Soft Tissue Thickness

Facial reconstruction is a scientific art to reconstruct the ante-mortem face using a human skull. The morphology of the skull is different from person to person and it is a factor which determines the unique facial appearances of people. Significant variations in facial appearances are dependent on the small variations of the shape, form and proportions of the skull. So, the facial reconstruction can be carried out by applying the average facial soft tissue thickness.

Throughout the history of facial reconstruction, various methods have been employed to determine facial soft tissue thickness (FSTT) values. Needle depth probing method was the most earliest and preliminary method which was used to measure the facial soft tissue thickness in the history. In the later years of the 20th century, following the development of modern technology, more recent and advanced methods were employed in taking soft tissue depth measurements. Advances in technology made it possible to significantly improve the quality and quantity of tissue depth data being measured. These advances include capturing digital data from living 3D images using ultrasound and cephalometric radiographs, under which fall magnetic resonance imaging (MRI) and computerized tomography (CT) scans.

2.2 Facial Soft Tissues and Landmarks

According to anatomy, the tissues that connect, support, or surround other structures and organs of the body, not being hard tissue such as bone come under soft tissues. Tendons, ligaments, fascia, skin, fibrous tissues, fat, and synovial membranes (which are connective tissue), and muscles, nerves and blood vessels (which are not connective tissue) are some examples for soft tissues [35]. Soft tissues on the face - the facial soft tissues - play a major role in the facial reconstruction since they are the main component which decides the shape of the face.

To measure the facial soft tissue thickness (FSTT) there are a set of locations called anthropometric landmarks where the FSTT is significant in facial reconstruction process. These can be identified on the skull, the bony tissue part of the head.

2.3 Acquisition of Data

2.3.1 Age Range Selection

The human face acts as a biometric tool for the identification of individuals [59]. Because of this reason, during the identification of an unknown decayed dead body or a skull in most of the cases, the facial reconstruction is followed. To identify the correct human face, the correct facial tissue thickness of the age which the discovered skull belongs should be identified. In addition, during plastic surgeries, when reconstructing the severely damaged face of a victim, the correct facial soft tissue thickness according to each age category should be identified. Due to above reasons, when creating a unified tissue thickness model for the facial soft tissue thickness, age plays a significant role. Because of this the selection of the age range for the creation of the tissue thickness model should be done carefully.

In 2014 Kaur M. et al conducted a study on facial soft tissue changes with aging [16]. They found that all the age related changes were found to be minimal in the individuals of age group 30–35 years and fair in 35–40 years age group. Marked changes were observed in individuals 40– 50 years of age and all these changes were prominent in individuals 50–60 years of age.

In 2007, Albert A.M. published the review of the literature on aging adult skull and face [17]. This research indicated that a significant change within the adults who are aged higher than 60 years does not occur. However the highest tissue thickness is recorded within the children and when considering the adults, it is recorded within the 20-30 age range. Below mentioned are the results presented in the aforementioned paper (Table 2.1).

Approximate age range (years)	**Likely bony change**	**Probable soft tissue of facial appearance effect**
20 - 30	Slight craniofacial skeletal growth Slight anterior (mostly lower) face height increase. Mandibular length increase	Upper eyelid drooping begins. Eyes appear smaller. Nasolabial lines begin to form. Lateral orbital lines begin to form. Upper lip retrusion begins in females
30 - 40	Dentoalveolar regression suggesting eruptive movement of teeth. Maxillary retrusion progresses, contributing to nasolabial folds.	Circumoral striae begin to form. Lines begin to form from lateral edges of nose to lateral edges of mouth. Upper lip thickness decreases.
40 - 50	Craniofacial skeletal remodeling progresses. Dental alveolar regression and dental eruption progresses. Maxillary and mandibular dental arch lengths decreasing	Facial lines and folds continue to increase in depth. Nose and chin positioning affected as dental arch lengths decreases. Most profound morphological changes of the head, face, and neck are evident
50 - 60	Craniofacial remodeling continues. Cranial thickness likely unchanging	Facial lines and folds continue to increase in depth. Protuberance of nose and ears due to greater craniofacial convexity.

>60	Decrease in craniofacial size. Greater craniofacial convexity (excluding maxilla and mandible). Possible temporomandibular joint arthritis and joint flattening. Alveolar bone remodeling continues	Protuberance of nose and ears continues. Concave appearance in cheek hollows due to Alveolar bone remodeling. Diminished jaws

Table 2.1- Adult hard and soft-tissue age-related changes

When referring the literature, we could identify most of the researchers have chosen varied age ranges and sample sizes. Below table summarizes the age ranges and sample sizes chosen by some of the studies (Table 2.1).

Study Name	**Age Range**	**Selected Age Groups**	**Sample Size per Each Range**
Facial soft tissue thickness database for craniofacial reconstruction in the Turkish adult population Bulut, O. et al. 2014 [18]	18 - 90 years	18- 29, 30- 39, 40- 49, 50- 59 and over 60 years	32 (Male - 16, female - 16)
Facial soft tissue thicknesses of the mid-face for Slovak population Panenkova, P. et al. 2012 [19]	18 - 87 years	18- 39. 40- 59 and over 60	
Midline facial soft tissue thickness database of Turkish population: MRI study Sipahioglu, S. et al. 2011 [8]	18 - 78 years	18- 34, 35- 45, 46- 55 and over 56 years	Around 38

Facial soft tissue thickness database of Gujarati population for forensic craniofacial reconstruction Lodha, A. et al. 2016 [10]	17 - 65 years	17- 25, 26- 35, 36- 45, 46- 55 and over 55	

Table 2.2- Age range and sample size of some past studies

By observing the literature, we found that the difference in the variation of FSTT within 20-59 age group is higher compared to age ranges below 20 years and above 60 years. Hence, this age range is used in this study.

2.3.2 Landmark Selection

When measuring the facial soft tissue thickness (FSTT), as mentioned in the above section, various methods can be used. The FSTT is measured at previously identified anthropometric landmarks. The number of landmarks included for each study of facial soft tissue thickness is determined according to the study to be carried out by the researchers. When referring the literature, amount of landmarks used for these studies range between 15 and 34 points. Most of the researches have used 31 landmarks for their studies. In some cases we can identify that some have used landmarks below 10 for their studies.

Study name	**Number of landmarks selected**
Craniofacial reconstruction using a combined statistical model of face shape and soft tissue depths: Methodology and validation Peter et al [20]	31 landmarks
Facial Soft Tissue Thickness Database for Craniofacial Reconstruction in the Turkish Adult Population Bulut O. et al[18]	31 landmarks
Large-scale in-vivo Caucasian facial soft tissue thickness database for craniofacial reconstruction De Greef S. et al[21]	31 landmarks

Facial Soft Tissue Thickness Database for Craniofacial Reconstruction in Korean Adults Hwang H. et al[3]	31 landmarks
Facial soft tissue thickness in northwest Indian adults Sahni DI, Sanjeev, Singh G, Jit I, Singh P.[22]	29 landmarks
Facial reconstruction: Soft tissue thickness values for South African black females D. Cavanagh, M. Steyn[6]	28 landmarks
Soft-tissue thickness of South Korean adults with normal facial profiles Kyung-Suk Cha [23]	21 landmarks
Analysis of Facial Skin Thickness: Defining the Relative Thickness Index Richard Y. et al[24]	15 landmarks
Evaluation of Soft Tissue Thicknesses with the Purpose of Facial Reconstruction in Brazilian Tedeschi-Oliveira S. V. et al[25]	11 landmarks
Midline facial soft tissue thickness database of Turkish population: MRI study Sipahioglu S.[8]	09 landmarks

Table 2.3- Number of landmarks included for different studies

In the early stages of this research following 30 anthropometric landmarks have been considered (As mentioned below). In this pilot research, attempts were taken to analyse skin tissue thickness patterns pertaining to the Sri Lankan population of the 20-30 age category. Therefore, in the current study the same set of landmarks are selected.

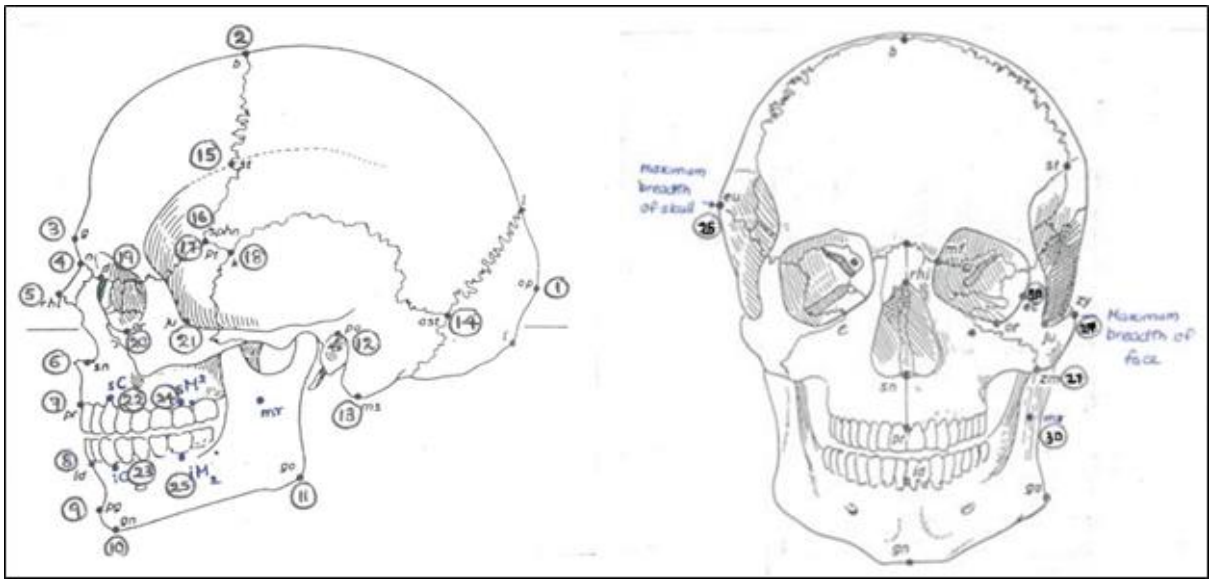


Figure 2.1 - 30 anthropometric landmarks used in the early stages of the research [40]

1. Opisthocranion
2. Top point on the skull
3. Glabella
4. Nasion
5. End of Nasal bone
6. Mid-philtrum
7. Upper lip margin
8. Lower lip margin
9. Mental eminence
10. Beneath Chin
11. Gonion
12. Supra glenoid
13. Mastoidale
14. Asterion
15. Stephanion
16. Sphenion
17. Pterion
18. Krotaphion
19. Supra orbital
20. Infra orbitale
21. Jugale
22. Supra-Canine
23. Infra-Canine
24. Supra M2
25. Sub M2
26. Euryon
27. Inferior malar
28. Ectocochion
29. Zygomatic arch
30. Maxillo-frontal

2.3.3 Data Collection Technique

Throughout the history of facial reconstruction, various methods have been employed to determine facial STT values. As mentioned before Needle depth probing technique was the most earliest and preliminary method which was used to measure the soft tissue thickness in sample cadavers. With the advancements of technology digital data were captured from in vivo samples using ultrasound and cephalometric radiographs [15], Magnetic Resonance Imaging (MRI) and Computerized Tomography (CT) scans.

2.3.3.1 Needle Depth Probing Method

The first research on facial soft tissue thickness was conducted as a part of facial reconstruction technique. Hermann Welcker during 1883 [29] carried out the first documented research on facial tissue thickness measurement. Under that he studied 13 white male cadavers of middle age and facial soft tissue thickness of 9 midline points was measured. There he used a double-edged, chisel-shaped knife blade pushed into the flesh of the cadaver to get the measurement. With the time, several improvements happened to this technique.

By adhering to this method, the tissue thickness of 40 corpses from São Paulo state, Brazil was measured [25]. Soft tissue thickness was measured by the needle puncture method in 10 craniometrical points and 11 bilateral points by 2 examiners within 12 hours from death to avoid any post-mortem distortion effect. Also in Australia, soft tissue thicknesses of a sample of cadavers were measured using this technology in year 2005[32]. Whenever certain limitations like access to live samples or inability to access new technological equipment to get the FSTT researchers tend use this traditional method. In addition to those reasons, since the subjects do not move, the equipment are easy to use, the measurements can be taken at any point of the subject and the researcher does not get exposed to the radiations, in 2009 Tedeschi-Oliveira et al. used the same method over 40 Brazilian cadavers, 26 males and 14 females [25].

Reliability of this technique is low compared to other methods as this method can only be used on cadavers and dehydration problems associated with cadavers which may lead to erroneous results. To eliminate such erroneous situations, methods like choosing people who had been deceased for less than 12 hours or who had only been refrigerated overnight should be followed as in 1980, Rhine and Campbell did[9]. However these methods are not capable of reducing the errors which can be occurred due to postmortem changes.

With the technological development, new methods were invented with the capability of measuring the FSTT thickness of live samples enhancing the accuracy of the FSTT measurements.

2.3.3.2 Ultrasound Technique

Ultrasound has been found useful and has been the method of choice for many modern researchers on soft tissue measurement as it is simple and inexpensive, requires no radiation exposure, and can be performed with the patient's seated position.

The very first ultra sound facial tissue thickness survey was published in 1985 by American researchers including Hodson [26]. Their research was done with 50 healthy American caucasoid children ranging from age 4 to 15.

In 2000, Manhein et. al used ultrasound technology to collect information from a sample of children and adults of the two sexes of varying age groups. Using state of-the-art ultrasound technology, they scanned 551 children and 256 adults at 19 points across the face for the purpose of increasing the available tissue depth data for children and updated facial tissue depth measurements for American adults [2]. In 2011 Wing Nam Joyce Chan also used ultrasonic measurements to conduct study to find the Facial tissue depths of Chinese-Americans in New York city [27]. In this research ultrasound measurements were taken at 19 landmarks across the faces of 101 individuals aged from 18 to 87 years.

Some criticism towards ultrasound is that the procedure requires a lot of training since it is difficult to interpret the images and control the equipment .Subjective errors may occur in the angulation of the ultrasonic probe with bone, since the angle to the bone at which the measurement is taken alters the value of the measurement, and holding the probe perpendicular to the skin surface does not necessarily mean that the depth will be measured

perpendicular to the bone. When the probe is pressed against the skin, it may cause some depression [15] of the skin surface and result in underestimation of the tissue thickness.

2.3.3.3 CT Scanning Technique

CT scanning is a technique that uses a computer to reconstruct a 3D image of the internals of an object from a large series of 2D radiographic images (axial and coronal slices). It has been particularly useful in anthropometric studies since it provides good definitions of both the skull and face images (Tilotta et al. 2009) [12]. High image contrast is seen between the bone (appearing white due to higher radio density) and subcutaneous soft tissues or musculature (appearing grey to dark), as well as the soft tissue versus air. One can clearly detect the margins of the bone and skin (Shimofusa et al. 2009) [34], making it possible to take an accurate measurement from a specific landmark on the bone to the surface of the skin.

In 1996, Phillips et al used the CT scanning technique to measure facial tissue thickness in a mixed racial population in South Africa. The research was done to a sample of 32 patients, 16 males and 16 females within the range 12 to 71 years [28].

CT scanning approach was used to measure the facial soft tissue thickness of North Indian adults by Tanushri Saxena, Sunil Ramchandra Panat, et al. (2012). A total of 40 individuals (19 males, 21 females) were evaluated using spiral Computed Tomographic (CT) scan with 2 mm slice thickness in axial sections and soft tissue thicknesses were measured at seven mid-facial anthropological facial landmarks under this study. [11]

In the research study, Facial Soft Tissue Thicknesses Prediction Using Anthropometric Distances by Quang Huy Dinh et al., a FSTT database was obtained using CT techniques. The researchers have adapted this technique as it is fast, accurate, can produce high quality images and the visualization of bony tissues is high in this technique. [31]

Department of Anatomy of University of Pretoriato, South Africa has done a research to develop soft tissue thickness (STT) values for South African black females for application to Forensic Facial Reconstruction (FFR), to compare these values with existing literature or databases and to add these values to existing population data. Computerized tomography

scanning was used to determine average population-specific Soft Tissue Thickness (STT) values at 28 facial landmarks of 154 black females. [6]

The Forensic Science department and Statistics department of the Gujarat University collaboratively conducted a study to construct a Facial soft tissue thickness database of Gujarati population for forensic craniofacial reconstruction in 2016 [10]. In this study Computed Tomography (CT-scan) technique has been utilized to measure the 25 different FSTT landmarks of 324 male and 165 female, ranging in age from 17 to 65 years under good health conditions. They were selected from patients arriving at Department of Radiology, Sheth V.S. Hospital, Ahmedabad, Gujarat and who required radiographic examination for treatment.

Europe has conducted a research with the aim of constructing a complete database, which is intended to improve the implementation and the evaluation of automated facial reconstruction. There sample is composed of 85 head CT-scans of healthy European subjects aged 20–65 years old. They have considered a set of 39 referenced anatomical skull landmarks were located manually on each scan. [12]

However not like ultrasound, the use of CT scanning is not easy. Since the CT scanners cannot be carried out here and there, the subjects should be directed to where the scanner is. Due to the radiation exposure, the sample should be selected through a voluntary process. To limit this in most of the studies the sample is selected through the patients who take CT scans for medical purposes.

Besides CT technique, literature indicate that Cone Beam CT (CBCT) as a new, reliable technology and alternative to CT technique. It offers better high spatial resolution, diminished ionizing radiation, and rapid data acquisition [43, 44, and 45]. Moreover. it allows patients to be in a seated position thus, reducing measurement distortion due to soft tissue displacement caused by the force of gravity [3], where values may diminish towards the anatomical landmarks of the medial line and increase towards the bilateral points when positioning the subject lying upwards during MRI, CT, and needle puncture. With this advantage this technique has been used to measure the facial tissue thickness of Colombian adults [30] where CBCT images of 30 living, adult subjects from both sexes (26 males and four females) between 18 and 35 years of age were used for the study.

Also in 2012, One hundred Korean adults (50 men, 50 women) were scanned in the upright position using a cone-beam CT (CBCT) scanner. The soft tissue (ST) thicknesses were measured at 31 landmarks and the means and standard deviations were obtained for male and female subjects. The CT scans were obtained using a CBCT scanner (Alphard Vega; Asahi Roentgen Co., Kyoto, Japan) with a voxel size of 0.39 mm and field of view of 200 (diameter). 179 (height) mm. The subjects were scanned in the seated position with a neutral, relaxed, facial expression. While the exposure time was 17 seconds, the subject's head was fixed using the head holder during the scan procedure so motion artifact could be prevented.

Yet, CBCT has the disadvantage of exposing the subjects to radiation as CT technique which can limit access to a considerable sample size [30].

2.3.3.4 MRI Technique

All the techniques (CT/ Ultrasound) have certain advantages as well as disadvantages. Added advantage of using the MRI technique instead of those techniques is that the soft tissue visualization is excellent over other methods and data can be viewed through 3D format [31]. Since this technology is new to research field the literature on the usage of MRI is considerably low.

A Preliminary Study on Facial Soft Tissue Thickness from Magnetic Resonance Imaging in Northwest Indians was conducted by Daisy Sahni , Indar Jit,et al. on 60 northwest Indian adults (30 women and 30 men) between the ages of 18 and 40 years in 2002 [33]. Seven MRI sections were taken to measure thickness at standard anatomical landmarks—one sagittal section, one parasagittal section at the level of mid orbit, two coronal sections, and three transverse (axial) sections. This study has concluded that Measurements of facial soft tissues of northwest Indian men are higher than northwest Indian women except beneath the chin, infraorbital margin, and lower lip margin. Significant variations of measurement were observed with sexual and racial differences.

A study was conducted to create a reference database of facial tissue thickness in the Turkish population by Serdar Sipahioglu a, Hakan Ulubay b, H. Barıs¸ Diren in 2011. The study included 161 patients (79 males and 82 females) between the ages of 18 and 78 who had undergone brain MRI. Measurements were taken at 9 points at the midline. Another aim of this study was to present data illustrating the successful use of MRI for this purpose. An odd number of sections were chosen for all patients and the researchers ensured that the middle section was the true mid sagittal section. T1-weighted (TR: 500 ms, TE: 15 ms, NE: 1) sagittal section measurements were used for the study. The T1-weighted sequence is preferred as it shows fat tissue and anatomical details more clearly [8].

In 2010, Feng Chen et al [41] used MRI scanning to collect data for their research. They collected a data sample of 425 subjects, 233 males and 192 females in the Chinese Xi'an Han population through MRI between age ranges 17 – 60 and above 60. A total of 31 landmarks together with 4 nasal profile parameters were taken from those MRI data. This study has revealed a unique facial profile of the Chinese Xi'an Han population. During the current study, they have found that, the average values at Rhinion, Inion and Opisthocranion points in Chinese Xi'an Han population are lower than other races in both sexes, while the Gonion point mean values are greater than other ethnic groups, except for Northwest Indians. Most of the measurement of craniofacial soft tissue thickness (CFSTT) in Brazilians and American blacks are slightly greater when compared to the Chinese Xi'an Han population, while all landmarks in Japanese have smaller values than the Chinese Xi'an Han population

In 2010 another study was conducted by Xiao Chen, Hong Zhou, Yuanyuan Zu conducted a research with a sample of 558 subjects [36]. There based on MRI technology, a series of 2D images of human head was obtained and their boundary coordinates were extracted respectively. After that a hierarchical 3D head parameterized model was constructed by fitting contours of all sections with Fourier series. The 3D standard head-face model was constructed, which could reflect the comprehensive features of specific population.

In CT scanning, the subjects get exposed to the radiation. Hence the sample of subjects should be taken from already available medical data repositories (not scanning people specially for the study). This will sometimes limit the availability of all the needed data. However in MRI that risk is not present since data can be collected with minimum

exposure to radiation. Yet the disadvantage of this method is, it is expensive than all other alternative methods.

2.4 Tissue Thickness Measuring Techniques

The advantage of using ultrasound technique over other techniques is the ability to measure the facial tissue thickness from the internal calipers of the ultrasound system. For the DICOM (Digital Imaging and Communications in Medicine) images collected from CT/MRI, a DICOM viewer software is needed to measure the facial tissue thickness.

Through the internal calipers of the Aloka SSD-500 OB⁄GYN ultrasound system the distance between the bone and the skin was measured in the research conducted for Chinese American adults in the New York city [27].As shown in the figure each ultrasound image which contained the measurements for two landmarks was then printed using a Sony Video Graphic Thermal printer (Figure 2.2).

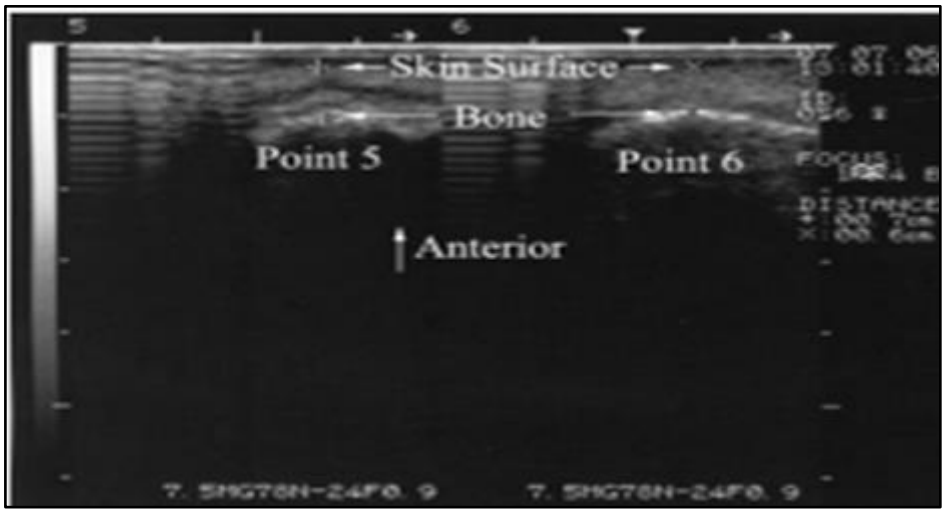


Figure 2.2 - Thermal printout of ultrasound data displaying measurements of 3 landmarks [27]

Ultrasound technology was also used in the research, Craniofacial reconstruction using a combined statistical model of face shape and soft tissue depths. Here the soft tissue depths at 52 cephalometric landmarks were measured with a compact and lightweight mobile digital ultrasound ‘‘A-mode’’ scanner (Epoch 4B with a 10 MHz 0.6 mm1 transducer, Panametrics Inc., Waltham,USA).[20].

Besides, ultrasound technique the major advantage of using high-resolution imaging methods such as CT and MRI is that they allow to capture and modification of cross-sectional images of complex anatomical structures and thus enable 3D soft-tissue measurement. By constructing either a 2D or a 3D model and locating the landmarks on the skull surface of the sample the tissue thickness can be measured. In the early stages of this research tissue thickness from CT images of 60 Sri Lankan adults (30 men and 30 women) ranging age from 20-30 years was measured using Osirix Lite software. [40]

In a study which was conducted to measure the soft tissue thickness of South Korean adults with normal profiles [23]. CT images were acquired from 40 individuals. Subsequently, a 3D model of the face was constructed with a 3D image-segmentation program named Mimics 10.01.The software used the existing coronal view to create cross-sections in the sagittal and frontal views. The HU (Hounsfield Unit- a quantity commonly used in CT scanning to express CT numbers in a standardised and convenient form) [37], which expresses the gray scale, was adjusted for each tissue in the CT system: 443 - 3,027 HU for the hard tissue and −700 - 225 HU for the soft tissue. The 3D volume rendering was performed by triangulation as shown in the figure.

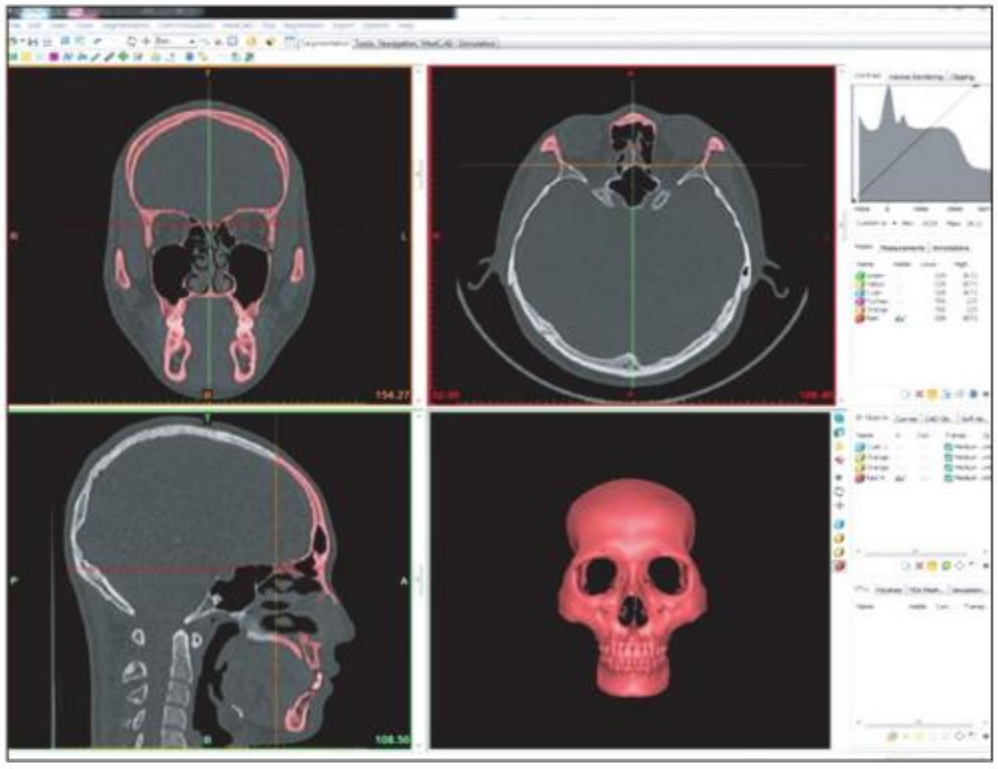


Figure 2.3-Method used for the three-dimensional computed tomography-image reconstruction [37]

Another study was done in Korea in order to establish a facial soft tissue thickness database for craniofacial Reconstruction in Korean adults. For the study data was collected using the CT scans that were obtained through the CBCT scanner. Maxillofacial 3D images were created from the DICOM data acquired from the CBCT scans and using V Works 4.0 (CyberMed, Seoul, Korea) (Fig.2.4). A couple of 3D object files were constructed with an adjustment of Hounsfield Unit (HU): one for hard tissue image with 550–650 HU and another for an ST image with 570 to 500 HU. Both soft and hard tissue images were imported into specific software, Skull Measure (CyberMed), to measure the distance between a point on the ST image and corresponding point on the hard tissue image.

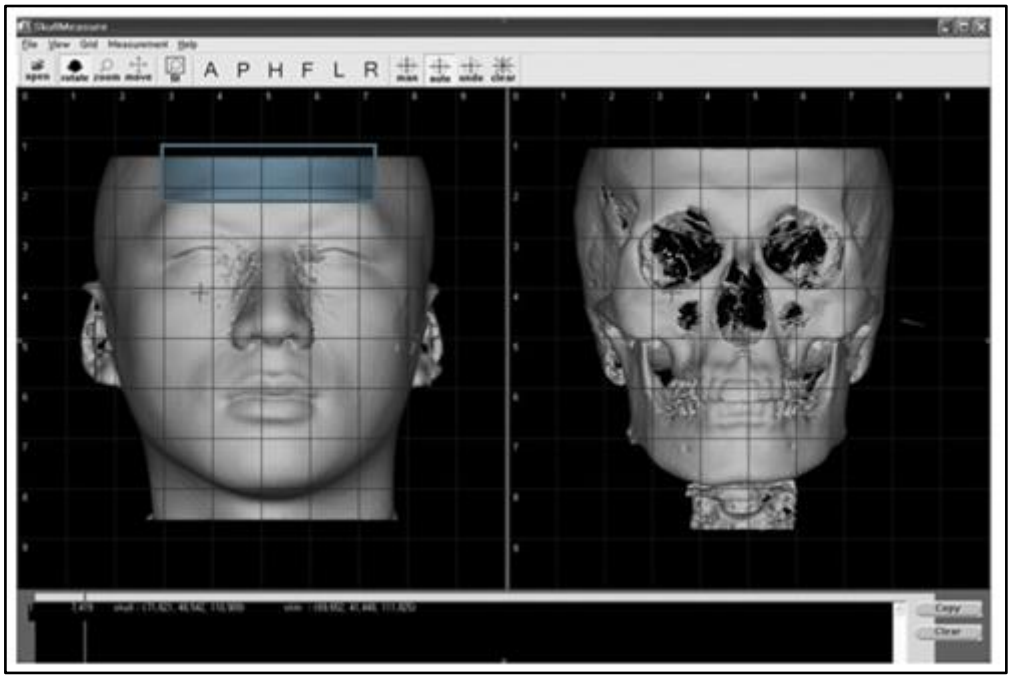


Figure 2.4 - A window of the Skull Measure program utilized to measure facial soft tissue (ST) depths from cone-beam CT images [3]

The DICOM images were exported to iCATVision software (Imaging Sciences International, Hatfield, PA, USA) to locate and measure facial thicknesses. Measurements were taken within 17 landmarks. The midline points were located in a sagittal view (Fig. 2.5) and the bilateral points in an axial view (Fig. 2.6). Facial soft tissue thickness measurements were made in millimeters, by following the methodology described by Cavanagh and Steyn [6] by tracing a line tangential to the bone surface and then a perpendicular line to that and

extended outward to meet the facial profile. Facial thickness measurements were performed in different order, with a 3-day space for every three images to diminish inter-observer and inter-observer errors.

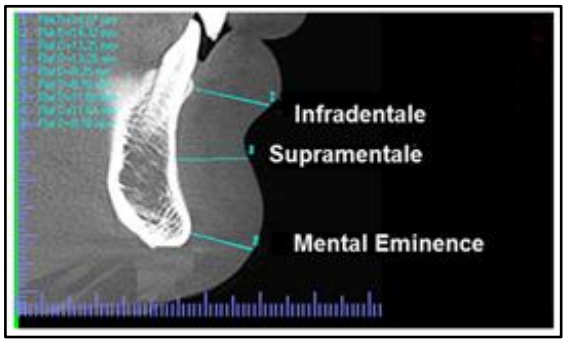


Figure 2.5 - Localization and measurement of some facial thickness in sagittal view (Infradentale, Supramentale, and Mental Eminence) [62]

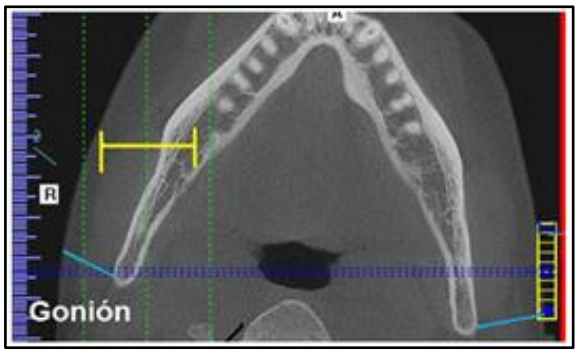


Figure 2.6 - Localization and facial thickness measurements in an axial view. (e.g., Gonion, in Light blue line) [63]

2.5 Data Analysis Method

After gathering the required amount of data sample researchers have processed the data using statistical approaches or computational methods. Below mentioned are the widely used data analysis approaches mentioned in the literature.

2.5.1. Statistical Analysis Approach

A statistical analysis was performed in Win Nam Joyce et al.'s study which was conducted on the Chinese American population in New York City to assess the relationship between FTT (Facial Tissue Thickness) and the age, gender and the BMI [27]. To analyze the

relationship between age and FTT Pearson's correlation and ANOVA techniques were used. Student's T test was performed to .assess the relationship between the FTT and the gender. Finally, to evaluate the relationship between FTT and the BMI Pearson's correlations and the ANOVA methods were used. For all statistical analyses the level of significance was $p<0.05$.

In Manhein's study which was conducted to analyse the tissue thickness of American adults, statistically analysed data for 515 children and 197 adults. Results of Pearson's correlation [2], analysis of variance, and paired t-tests indicated that age, sex, and race are significant factors when considering tissue depth means for different measurement locations across the human face.

In the study conducted for Turkish population [8] using MRI measurements, results were evaluated using Statistical Program for Social Sciences (SPSS) .The mean, standard deviation, and range were calculated for all measurements. Males and females were classified according to their age and BMI and the variation of the tissue thickness was compared against these parameters. Statistical analysis was conducted using one way ANOVA and independent T test and $p < 0.05$ was considered significant.

In the research study, "Facial Soft Tissue Thicknesses Prediction Using Anthropometric Distances" by T. Bui et.al. data processing was done using linear regression[31]. This statistical method has been used to model the relationship between two variables, the anthropometric distance and the thickness at each anthropometric landmark by fitting a linear equation to the observed data, In the linear regression line $y= a+bx$, X is one of the distances in input set and Y is one of the thicknesses in output.

In the study which was conducted to create a Facial soft tissue thickness database for Gujarati population [10] the resulting data were recorded in Excel Spreadsheet and statistical analysis was done by IBM SPSS Statistics 20 software. One way ANOVA test was used to determine whether there is any significance between the means of two or more independent groups or samples. The discriminant function analysis was done with the use of SPSS software to find out the ability of all these parameters to differentiate between sexes. The t-test was performed to determine if there is a significant difference between the mean or average scores of two groups male and female. 5% of significance level was chosen for performing the test to derive the p-value.

2.5.2 Neural Networks Based Analysis

In the research study by T. Bui et.al which was conducted to measure the facial tissue thickness using anthropometric distances, data processing was done using artificial neural networks with parallel to the statistical analysis [31]. Multilayer perceptron is the artificial neural network type used in this study. It is a feedforward artificial neural network model that maps set of input data onto a set of appropriate output. For each thickness in output, the correlation coefficient was calculated for the matrix combined of input and the thickness to realize the distances in input that have high correlation with the thickness. Weights were initialized randomly and the neural network was trained for several times with 10-20 neurons.

2.6 Tissue Thickness Model

Literature does not indicate any statistical model for the facial soft tissue thickness. To the best of the authors' knowledge there is no sufficient literature on research work that have been conducted with regard to statistical modelling using tissue thickness data. However there are several papers which present statistical models for other biological study areas. The following paper by H. Rahmandad [50] presents a study on generating a model to capture changes in body weight, composition and height within the lifespan of an individual.

Under this paper, it presents the first mechanism-based model spanning full individual life and capturing changes in body weight, composition and height. Integrating previous empirical and modeling findings and validated against several additional empirical studies, the model replicates key trends in human growth including A) Changes in energy requirements from birth to old ages. B) Short and long-term dynamics of body weight and composition. C) Stunted growth with chronic malnutrition and potential for catch up growth.

Three state variables are used for this purpose as fat mass (FM), fat free mass (FFM) and height (H). FM and FFM suffice for modeling longer term dynamics, while more detail is required for capturing hourly and daily dynamics. A third state variable, height (H), allows this model to account for variations in height and the potential for stunted growth as a result of malnutrition. Inclusion of height also facilitates the use of BMI, rather than weight, in specifying reference inputs for the model and analyzing obesity and other conditions. There is

less variation in BMI than there is in weight, making the resulting reference curves more robust. Indicated body weight (BW) is calculated based on the indicated height and the indicated body mass index (BMI)

The indicated BW is partitioned into indicated FM and FFM (FM and FFM) based on an empirical equation, which calculates the most likely Fat Mass Index (FMI) for any given BMI value. It bases its estimates on reference values of FMI (FMIRef) and modifies those based on individual's BMI status (BMIRef-BMI) and race.

This study provides the first mathematical model of growth and body composition during infancy and early childhood; integrates the height dynamics with the weight and body composition modeling; and building on growth canalization and energy allocation offers an alternative architecture for modeling body weight, composition, and height with distinct features.

2.7 Evaluation

Once the statistical model is built and the facial reconstruction is completed its accuracy should be checked.

2.7.1 Leave- One-Out Approach

In the research 3D statistical facial reconstruction [38], mentioned previously, leave-one-out approach has been used to test the accuracy of the results. The learning database is composed of all subjects minus one, which is the test sample. Every subject became the test sample in turn. In all cases the global reconstruction was correct. The face was constructed with an accuracy of 0.5mm for the samples in the learning database. The same approach has been followed in the research 3D Semi Landmarks- Based Statistical Face Reconstruction [39].

Leave one out cross validation has also been used in the research, Craniofacial reconstruction using a combined statistical model of face shape and soft tissue depths [20]. Here, each facial sample was removed, in turn, from the database (A 3D facial entry (sample)

in the database consists of a 3D skin surface representation coupled with soft tissue depths) and used as a test case. The remaining facial entries were used to create the statistical model. A quantitative reconstruction error evaluation was performed by calculating the distances between every point on the reconstructed skin surface and its closest point on the measured skin surface of the test case. Through this an average absolute reconstruction error and standard deviation, which could be visualized for every point on the reconstructed skin surface were obtained.

2.8 Conclusion

Facial soft tissue thickness is an important factor which determines the facial reconstruction of individuals. Research indicates that there are several methods to collect samples to measure the soft tissue thickness values. Ultrasound, MRI and CT are widely used techniques at present. Each method has its advantages over disadvantages. By studying the literature we can conclude that MRI is the best technique to construct a 3D model and measure the tissue thickness as the soft tissue thickness visualization is high in MRI neuroimaging data.

When gathering data using neuroimages, some FSTT values may not be calculated as some FSTT values will not be able to measure from the available samples. Especially if data is not collected specifically for the study and collected from established clinical databases at medical institutes, it would not be possible to cover all tissue thickness points which are needed for the study. To overcome this issue statistical interpolation can be done with the aid of statistical analysis and learning methods. For the t statistical analysis studies in the literature have used Anova, Pearson's correlation techniques and Student's T test to analyse the relationship between FSST and the other variables (age, gender, BMI). Also some studies have used linear regression method to model the relationship between two variables. Out of those studies majority has taken SPSS software for the statistical analysis purposes.

Few studies have used machine learning techniques to the data processing in FSTT analysis. Those studies have proved that, as the neural network has the ability to find patterns and irregularities, as well as detecting multi-dimensional nonlinear connections in data,

applying neural networks to predict the soft tissue thicknesses for facial reconstruction will produce better output over the other techniques.

Sources don’t indicate about any FSTT models built for foreign context. But, few studies have developed statistical models using biological data.

3. Chapter 3- Methodology

This chapter describes in step by step the design and methodology of the research.

3.1. Research Design

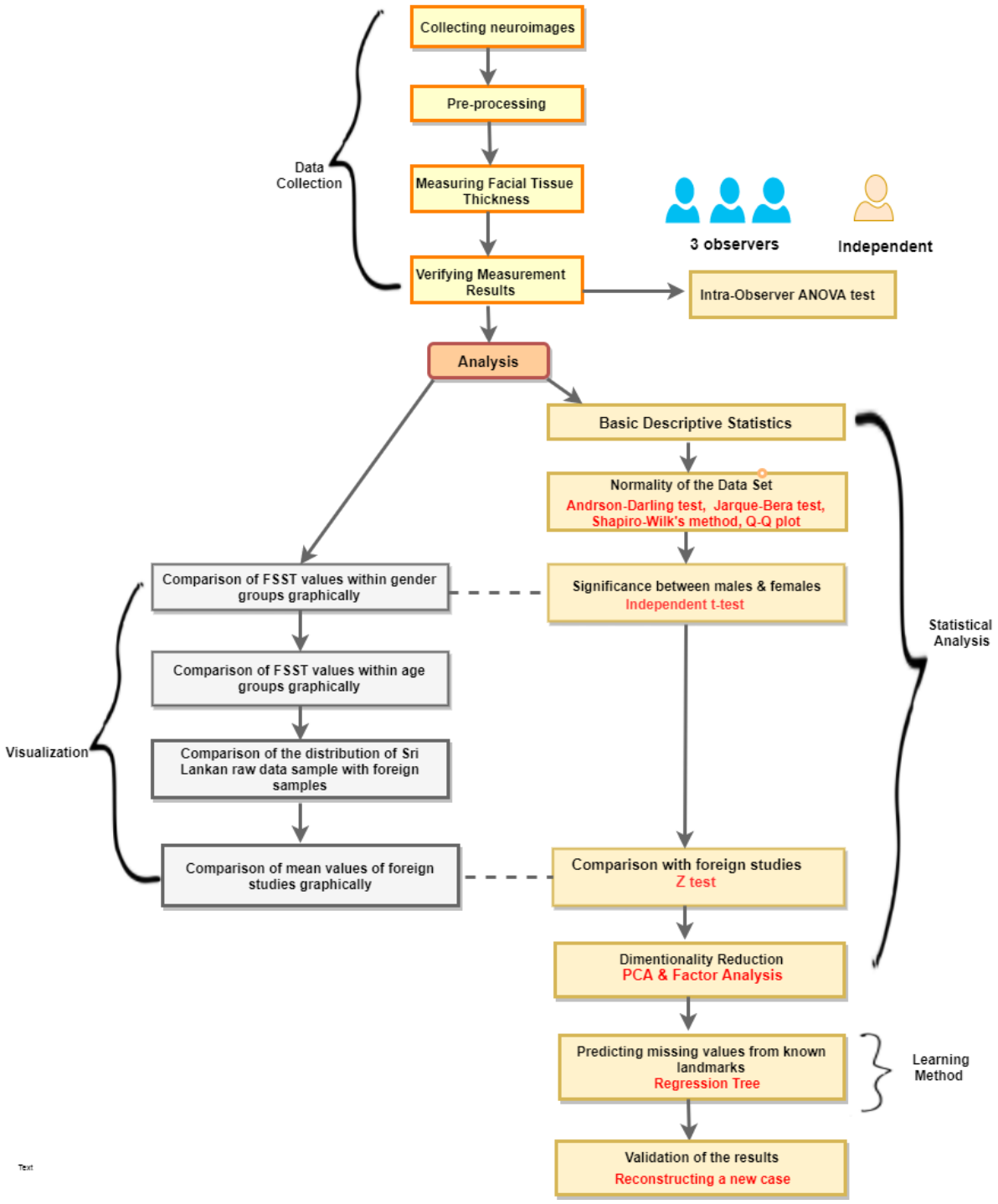


Figure 3.1 - Research Design

The diagram 3.1 shows how the research is structured. The latter part of the section describes the components of this structure.

3.2. Development of Facial Soft Tissue Thickness values: Data Collection

3.2.1 Introduction

The initial part of the study aims to develop Facial Soft Tissue Thickness values for Sri Lankan adult population. A person could be identified through special features which are unique to his or her own face. Accordingly, it is important to measure the thickness of such areas which covers the face. Landmarks have been chosen from the frontal, three-quarter and lateral profiles seem to be the most descriptive and typical of a person (Aulsebrook et al. 1996[15]).

3.2.2 Materials and Method

MRI scan reports from National Hospital Colombo (Siemens Harmony) were used to obtain the measurements of FSTT. The sample comprised of 243 MRI scan reports of 20-59 age range. (Table 3.1 shows the number of sample collected from each age category).Patients with head trauma, fractures, swellings, asymmetries, distortions, malformations or any abnormality that could influence the shape of the face or thickness of the subcutaneous tissues and musculature, were eliminated from the sample (Sahni et al. (2008) [21]) Since the FSTT measurements of most of the landmarks around the jaw area were unable to take (due to the unavailability of images around the jaw area) a sample of 20 Volume MRIs were also obtained from the National Hospital Colombo.

Before obtaining the MRI sample from the hospital, the approval from the ethical committee of the National Hospital Colombo was received, with the provision that all the patient information obtained during the course of this study will be treated as strictly confidential. Any information that can be useful in identifying the patients, are not included in any of the documents related to this study.

Measurements were taken from the Sagittal, Coronal and Axial planes of the MRIs. Besides, T1 and T2 views of the aforementioned planes were used for measuring purposes. Patient details namely the weight and height were not provided along with the MRIs though the age was recorded.

Age Group	Male	Female
20-29	19	23
30-39	20	34
40-49	27	28
50-59	40	27
Total	218	

Table 3.1- No. of samples obtained per each category

Image Preprocessing - Before getting measurements it was vital to perform image preprocessing as the clarity of bony and soft tissue regions of certain images was poor. Image preprocessing was done using the Canny Edge Detection method of MATLAB R2013b [49]. The reason for choosing Canny method over other edge detection methods is it uses two different thresholds (to detect strong and weak edges), and includes the weak edges in the output only if they are connected to strong edges. Therefore, this method is more likely to detect true weak edges.

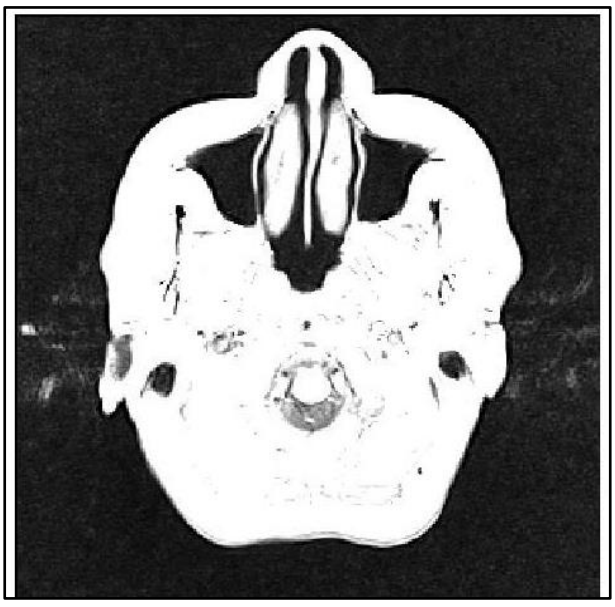


Figure 3.2 -Before applying canny edge detection

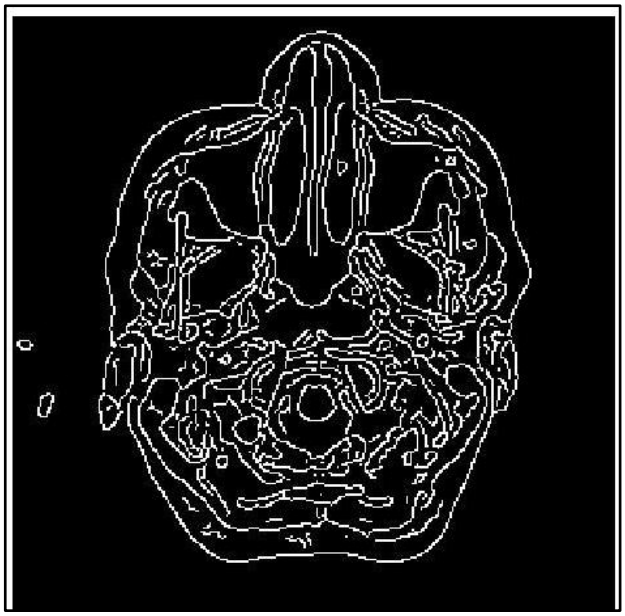


Figure 3.3 -After applying canny edge

3.2.3 Measurements

Measurements were taken using the tool RadiAnt DICOM Viewer (3.4.2). When taking the measurements as the first step, required 2D MRIs were loaded to the RadiAnt Viewer and required view (either T1 or T2 Sagittal/ Axial/ Coronal view) was selected. Then the required bony landmark was located on the hard tissue visualized in the MRI. During the early stages of this research the measurements were done using the 3D view of the CT images. As the MRI images do not support with the 3D view, for the current study, the measurements were done using 2D view.

Then a tangent was drawn to the curve of the outer surface of the selected bony landmark (Line "A" in the below figure). A line was drawn perpendicular (measuring 90^0 from the bony landmark) to the tangent at the bony landmark and extended outward to meet the facial skin surface (line "B" in the below figure). The length of the line (Euclidean distance) from the bone to the junction with the skin surface was regarded as the equivalent FSTT of that landmark (As shown in the below figures). The FSTT recorded is the Euclidean distance between the bony landmark and its homologous cutaneous landmark. All the measurements were taken to the nearest 0.01 mm.

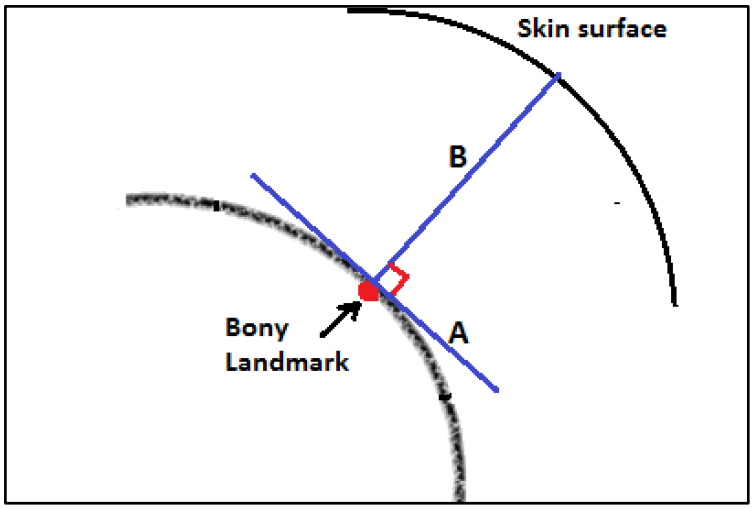


Figure 3.4 - Diagrammatic representation of establishing tissue thickness measurements

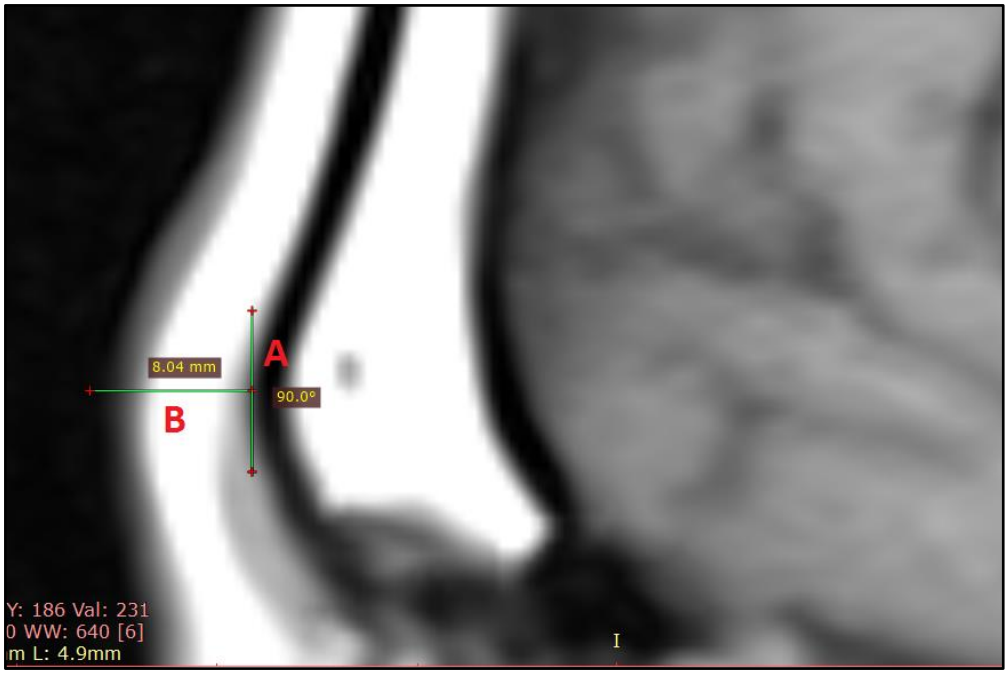


Figure 3.5 - Establishment of FSTT measurements on MRI

(This shows the measurement of the landmark Nasion. Line "A" is drawn tangential to the bony landmark and line "B" drawn perpendicular to line "A")

In order to maintain the accuracy of the measurements, 10 subjects were selected randomly, and the measurements were repeated by the three observers individually. To assess the inter-observer variability, ANOVA F test was performed using IBM SPSS Statistics 20.

3.2.4 Landmarks

For this study tissue thickness of 22 biometric landmarks were defined. These landmarks are defined and used traditionally in forensic facial reconstruction. As well these are set of landmarks defined in the early stages of this research. For the process of identifying biometric landmarks in MRI 2D images and for tissue thickness measuring purposes, we got the domain knowledge from the following experts in field of anatomy, forensic medical and neuroradiology - Dr. P.H. Dissanayeka (Department of Anatomy, Faculty of medical Sciences, University of Sri Jayawardenapura), Dr. Sajith Edirisinghe (Department of Anatomy, Faculty of Medical Sciences, University of Sri Jayawardenapura), Prof. M. Vidanapathirana (Professor of Forensic Medicine, Department of Forensic Medicine, Faculty of medical Sciences, University of Sri Jayawardenapura) and Dr. Aruna

Pallewatte (Consultant Neurologist, Department of Neuroradiology, National Hospital of Sri Lanka.

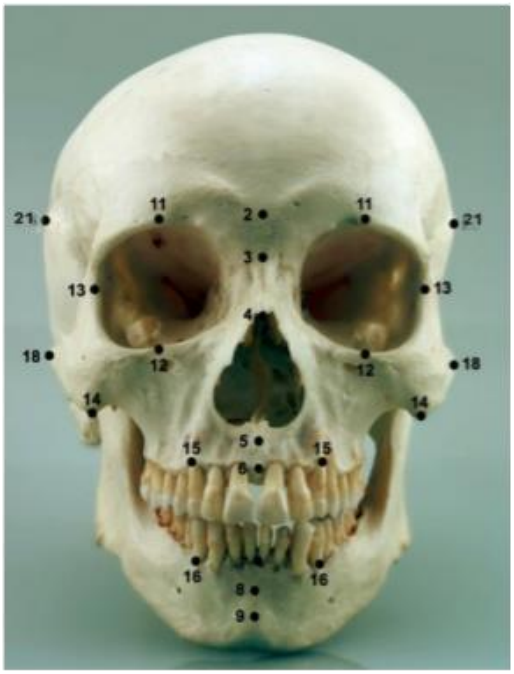


Figure 3.6- Frontal view landmarks for markers measurements or location of tissue depth

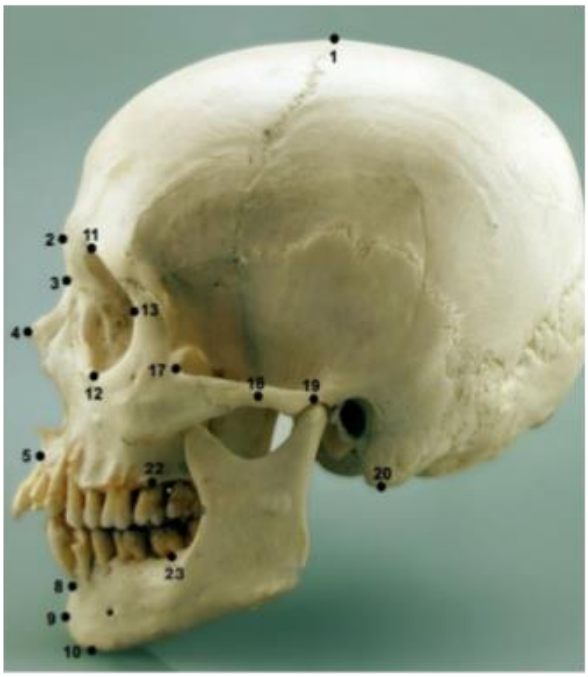


Figure 3.7- Lateral view landmarks for markers measurements or location of tissue depth

Following table shows the defined landmarks for measurements and location of tissue depth markers [46, 47, 48].

Landmark No.	Landmark Name	Description
1.	Bregma (Bre)	The point where the coronal and sagittal sutures intersect [46]
2.	Glabella (Gla)	Cross point between midline and supraorbital line [46]
3.	Nasion (Nas)	Midpoint of the frontal nasal suture [46]
4.	End of nasal bone (End)	Passage between bone and cartilage of the nose
5.	Mid philtrum (Mid)	Centered between nose and mouth on midline

6.	Upper lip (Upp)	Midline on the upper lip
7.	Lower lip (Low)	Midline on the lower lip
8.	Chin lip fold (Chi)	Midline centered in fold chin, below lips
9.	Mental eminence (Men)	Centered on forward most projecting point of chin
10.	Beneath chin (Ben)	The vertical measure of the soft tissue on the lower edge of the chin
11.	Supra-orbital (Sup)	A point above the orbit, centered on the uppermost margin or border of the orbit
12.	Infra orbital (Inf)	A point below the orbit, centered on the lowermost margin or border of the orbit
13.	Ectoconchion (Ect)	The intersection of the most anterior surface of the lateral border of the orbit and a line bisecting the orbit along its long axis.
14.	Supra-canine (SCa)	Upper lip lined up superiorly/ inferiorly with lateral edge of the nostril.
15.	Infra-canine (ICa)	Also known as Sub Canine. Lower lip lined up superiorly/ inferiorly with lateral edge of the nostril.
16.	Jugale (Jug)	The point in the notch between the temporal and frontal process of the zygomatic bone
17.	Zygomatic arch (Zyg)	A point on the maximum lateral outer curvature of the zygomatic bone, also known as the zygion (Rhine and Campbell 1980[9]; Aulsebrook et al. 1996[15]; Phillips and Smuts 1996[28]; Wilkinson 2004; De Greef et al. 2006[21])
18.	Supra-glenoid (Gle)	A point above and slightly forward of the external auditory meatus (Rhine and

		Campbell 1980[9]).
19.	Mastoidale (Mas)	A paired point at the inferior tip of the mastoid process.
20.	Euryon (Eur)	The most laterally positioned point on the side of the braincase. Euryon always falls on either the parietal bone or on the upper portion of the temporal bone and may be determined only by measuring maximum cranial breadth.
21.	Supra M2 (Spm)	A landmark above the second maxillary molar
22.	Sub M2 (Sbm)	A landmark below the second mandibular molar

Table 3.2 - Description of the 22 landmarks used in the research

The detailed descriptions of the landmarks indicated in above table and description on how these were measured are included in the Appendix.

3.3. Calculating Basic Descriptive Statistics

The resulting measurement data were recorded in Excel Spreadsheets and statistical analysis was done by IBM SPSS Statistics 20 software. Basic descriptive statistics such as the mean, standard deviation, range, maximum and minimum of soft tissue thickness value for male and female calculated separately for each age group were reported.

The mean determines the average facial tissue thickness for each landmark. The minimum and maximum is given for each measurement to give an idea of the variation in the subjects who have been measured in this study. The range was calculated as the difference between the minimum and maximum for each data set. The standard deviation is also a value that indicates variability of the measurements to the mean, that is, how far the data points lie from the mean.

After the calculation of the basic descriptive statistics comparisons among age groups, gender groups and with established foreign studies were done using visualizations. The results were further analysed using statistical tests.

3.4. Comparison of FSTT of the Sri Lankan Population within Age Groups, Gender Groups and With Foreign Studies

3.4.1. Comparison of Sri Lankan Facial Tissue Thickness Values within the gender groups

3.4.1.1. Graphical representation of the FSTT variations between gender groups

The below graphical illustrations show the comparison of the Sri Lankan FSTT values within 2 gender groups of the 4 selected age categories. The trend lines were drawn using pchip (Piecewise Cubic Hermite Interpolating Polynomial) spline [58] drawing method of MATLAB R2013b. Similar kind of graphical representation was done to represent the comparison within age groups and foreign populations also.

It should be pointed out that trend lines were only drawn for the ease of observation of the variation between two groups and no any inference from the trend lines has been done [57].

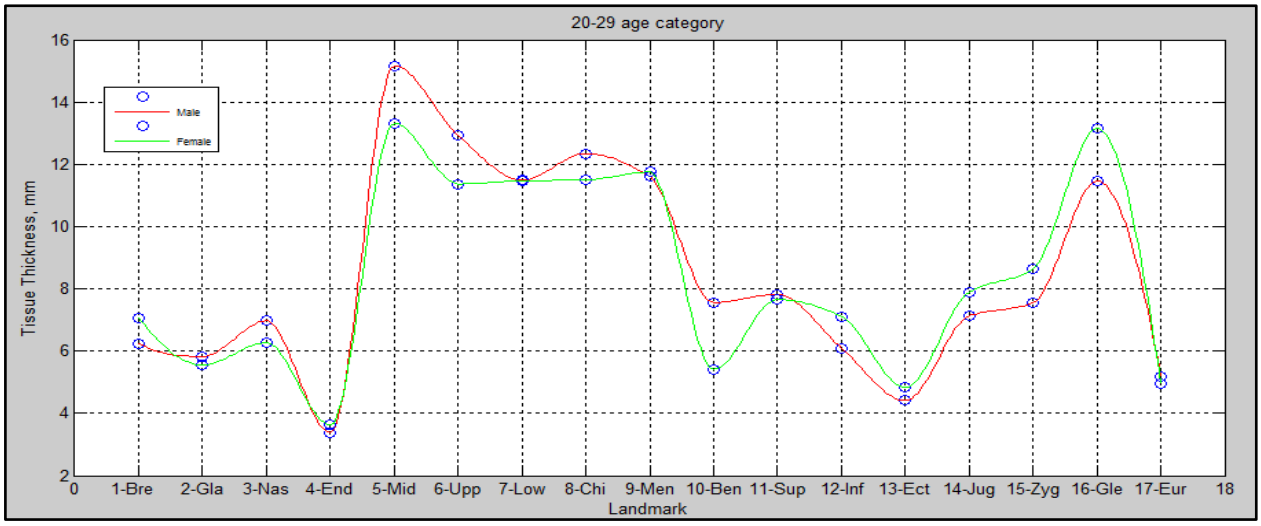


Figure 3.8- Variation of FSTT of both genders for 20-29 Figure age range

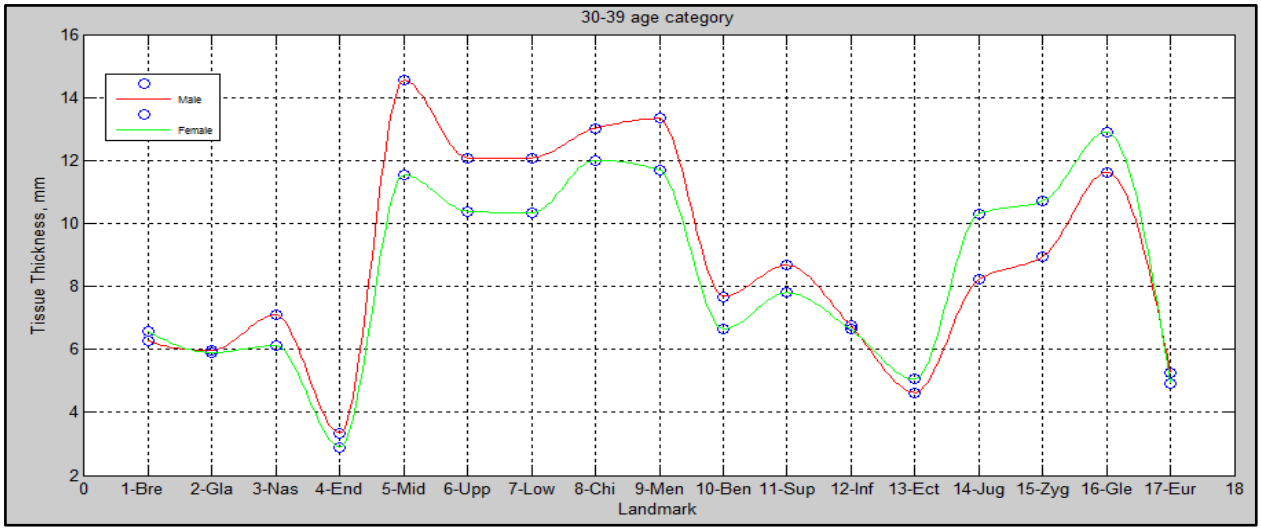


Figure 3.9 - Variation of FSTT of both genders for 30-39 age range

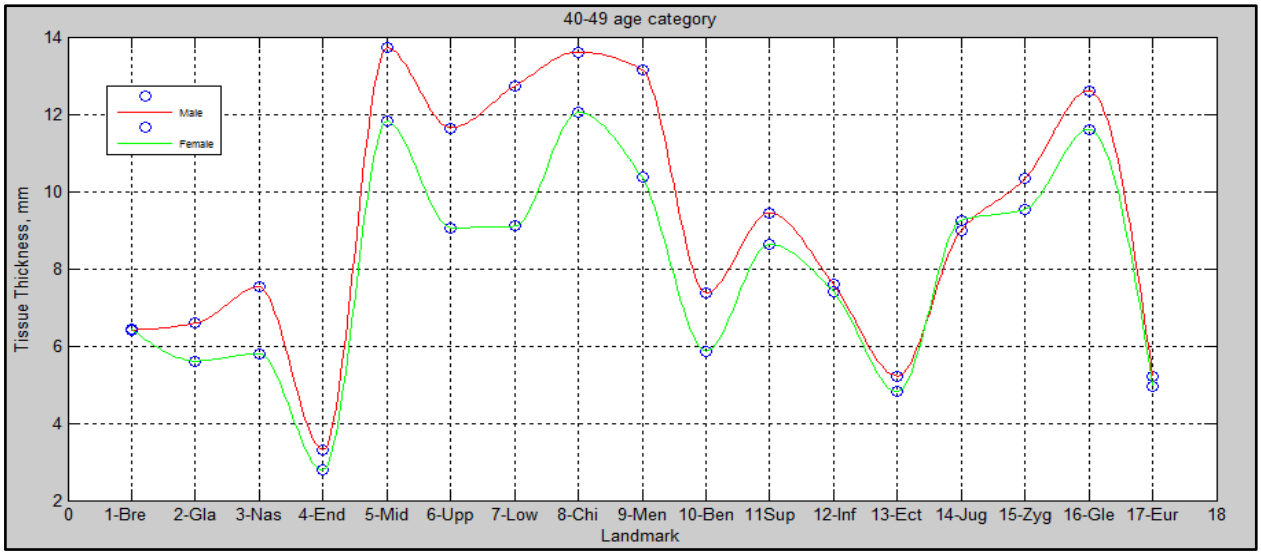


Figure 3.10 - Variation of FSTT of both genders for 40-49 age range

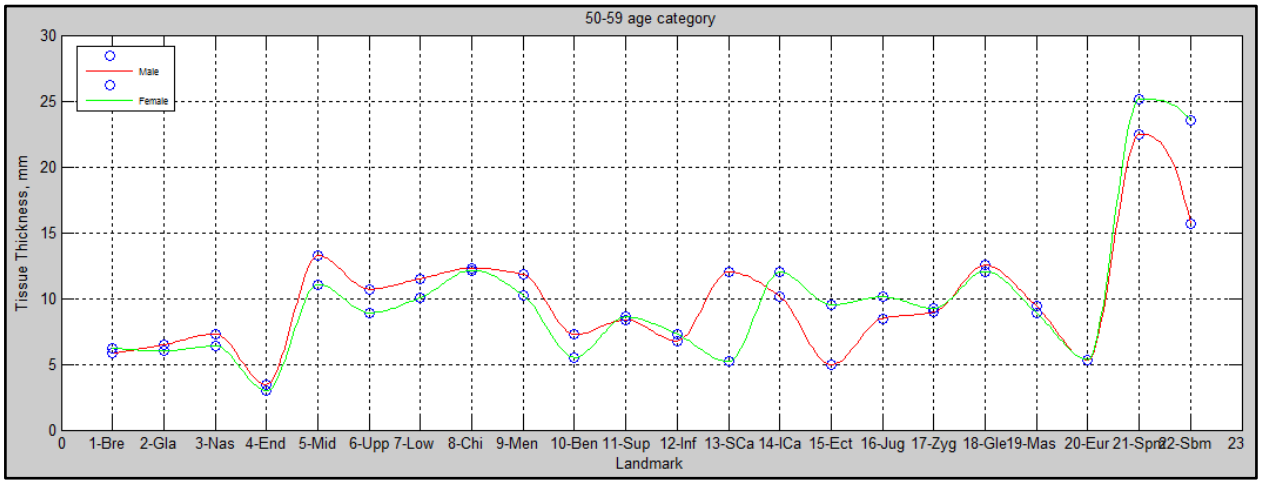


Figure 3.11 - Variation of FSTT of both genders for 50-59 age range

3.4.1.2. Statistical Analysis of the FSTT Variations between Gender Groups

Further analysis of the above graphical representations was done using statistical analysis in order to claim the validity of the results. .For the purpose of analysing the influence of gender on facial soft tissue thickness at each landmark, literature has used Student's t-test (Independent t-test) [10]. There, a comparison of males and females at facial tissue depth landmarks can be done in order to find the type of correlation between gender and tissue thickness.

Before performing all the statistical tests the normality of the testing groups were tested using statistical normality tests.

3.4.1.2.1 Normality Test

In order to perform statistical tests (T test, Z test) it was important to claim that the Sri Lankan sample is normally distributed. So, to find the normality of the Sri Lankan data set, four tests namely Jarque-Bera test, Anderson - Darling test, Shapiro-Wilk's and Q-Q plot test were performed using the software R x64 3.4.1. For the Anderson darling test, "nortest" library was used. When performing the Jarque-Bera test, the "tseries" library was used. Also in order to evaluate the normality using the Q-Q plot it was required to use "dplyr" and "ggpubr" libraries. Results of the Normality tests are included in the Results chapter (4.4).

See Appendix A for the script written using R to check the normality of the samples using the 4 tests

3.4.1.2.2. Independent t-test (Student T test)

Independent T test (Student T test) was performed using IBM SPSS Statistics 20 software to measure the significance between male and female categories. Here the normality of the male and female samples was assessed and proved by conducting normality tests for male and female gender samples separately. Also it was assumed that the female and male gender groups are independent.
The results of the above analysis are included in the Results chapter.

The results of the Levene's test indicates whether the variances of the 2 gender groups are equal or not ($P<0.05$). When the variances were equal the significance column of the T

test corresponding to the **Equal variance assumed** row was considered. When the variances were not equal the significance column of the T test corresponding to the **Equal variance not assumed** row was considered. [52]

The formula for T statistic when Equal variances assumed [52],

$$t = \frac{\overline{x}_1 - \overline{x}_2}{s_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

1

Where,

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

2

The T statistic when equal variances are not assumed [52],

$\underline{x}_1$=Mean of male sample

$\underline{x}_2$=Mean of female sample

n_1= Sample size (i.e., number of observations) of male sample

n_2= Sample size (i.e., number of observations) of female sample

S_1 = Standard deviation of male sample

S_2 = Standard deviation of female sample

S_p= Pooled standard deviation

3.4.2. Comparison of the Sri Lankan Facial Tissue Thickness Values within Age Groups

3.4.2.1. Graphical Representation of Comparison with the Distribution of Sri Lankan Raw Data

A graphical illustration was done to compare the FSTT values within the four selected age groups (separately for 2 gender groups) in order to analyse the pattern of variation of the tissue thickness with aging. All the graphical representations were done using MATLAB R2013b software.

Sri Lankan Male population

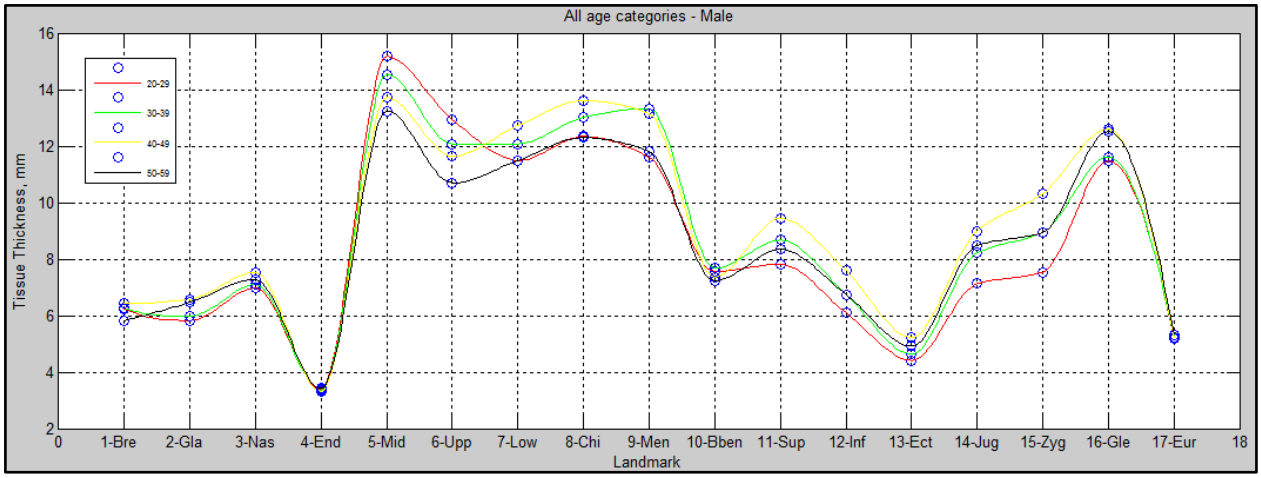


Figure 3.12 - Variation of FSTT with aging- Male population

Sri Lankan Female population

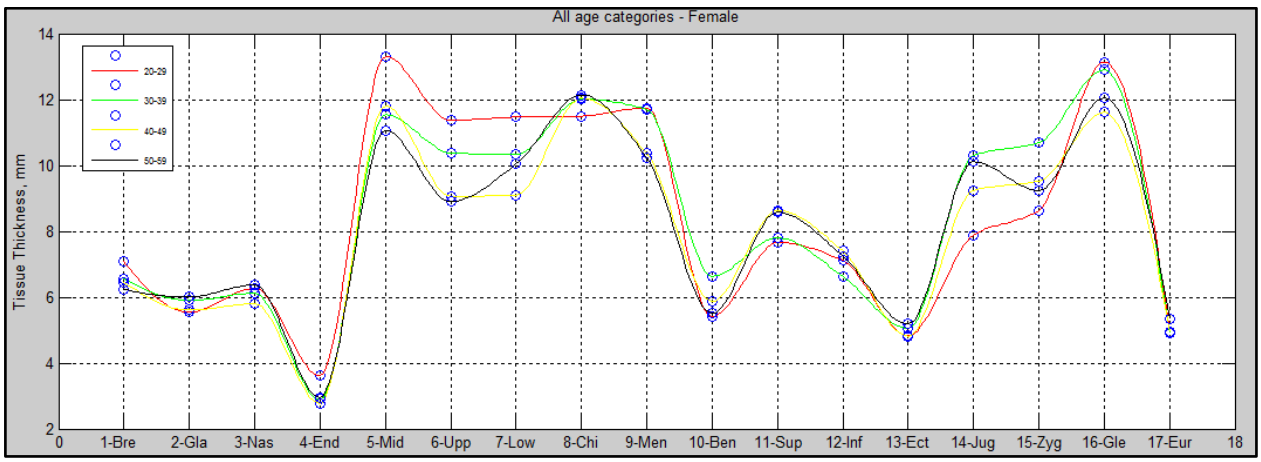


Figure 3.13 - Variation of FSTT with aging- Female population

3.4.3. Comparison of Sri Lankan Facial Tissue Thickness Values with Established Foreign Studies

One of the main objectives of this research is to assess the possibility of devising a unified facial tissue thickness model by interpolating missing FSTT values of the current study using the data of other published foreign studies. Same kind of comparison was performed by A.Lodha et al.'s study for Gujarati population [10], Wing Nam Joyce Chan's study for Chinese American adults [27] and Pierre Guyomarc'h et al's study for French population [14].

In order to perform statistical interpolation it was needed to select the foreign study which shows less variation with the data of the current study. For this purpose, data was compared with that of the results of Chung et al.'s study (Taiwanese population) [51], Bulut et al.'s study (Turkish population) [18] and Sahni et al.'s study (North West Indian population) [22]. The reason for selecting these three foreign studies is that the age groups selected in these studies do tally with that of the Sri Lankan study and descriptive statistics were available along with the research publications. Also, all the three countries are from the Asian continent which aided us to stand on the assumption that the three populations would have some similarity in their FSTT.

Both graphical representation and statistical analysis was done to understand FSTTs reported by which foreign study variates less with the FSTTs reported by the Sri Lankan study.

3.4.3.1. Graphical Representation of Comparison with the Distribution of Sri Lankan Raw Data

Here the distribution of raw data was plotted for each age category with the mean values of the foreign studies in order to understand which study shows the highest relationship with the current study. Excel Spreadsheets were used for the below representation.

The following colour code is used in charts in the below subsections.

NW Indian	
Taiwanese	
Turkish	

SL mean	
SL raw data distribution	

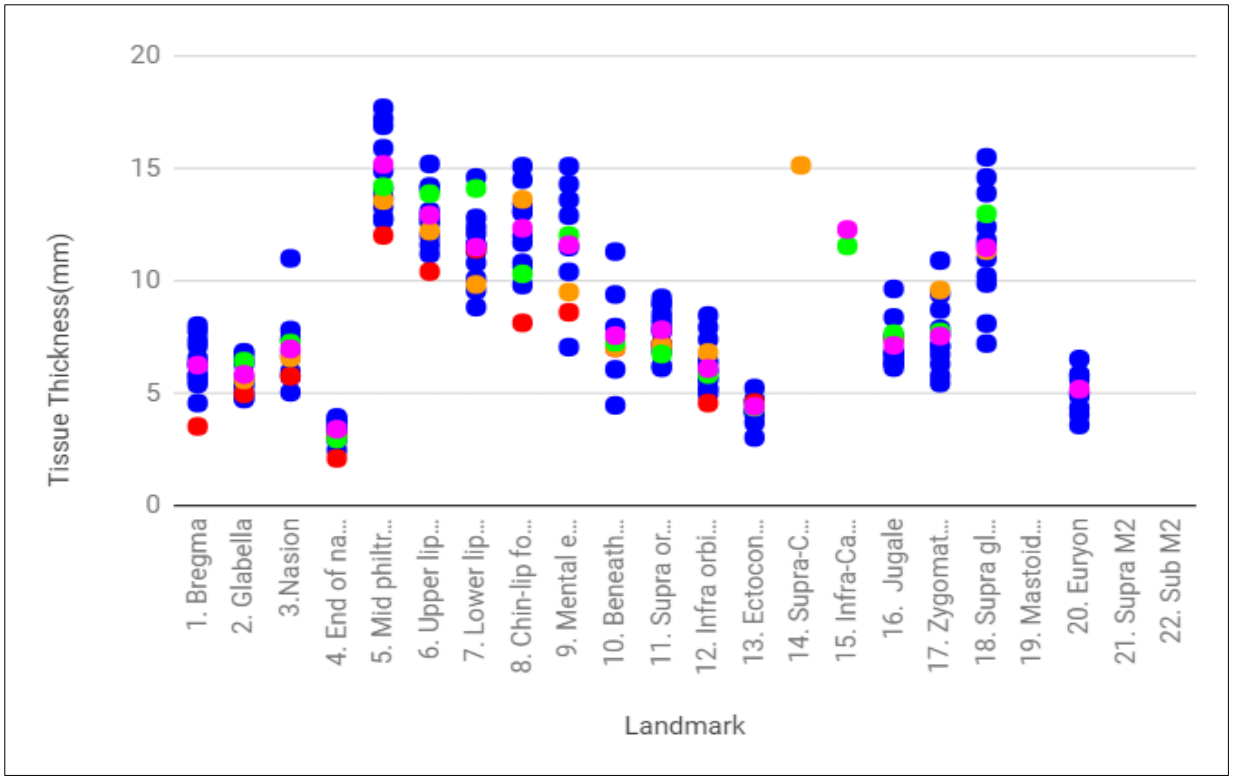


Figure 3.14 – Scatter plot for 20-29 Male population

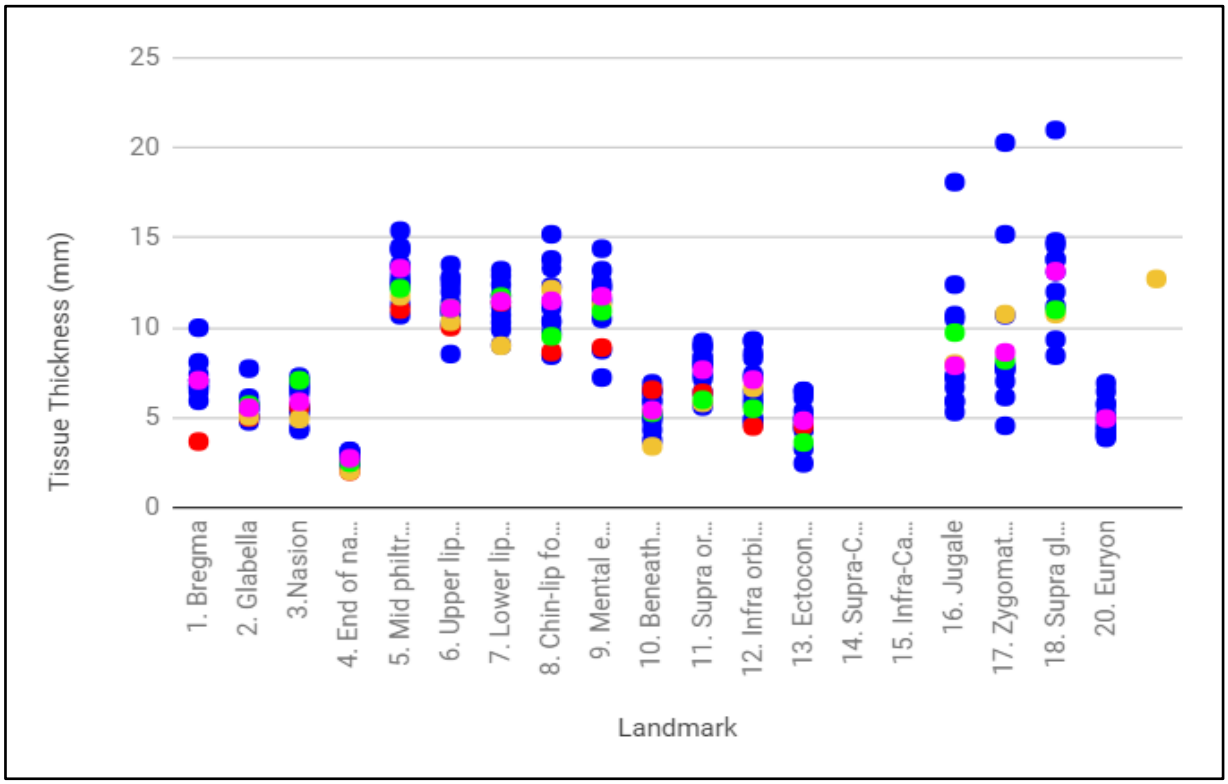


Figure 3.15 – Scatter plot for 20-29 Female population

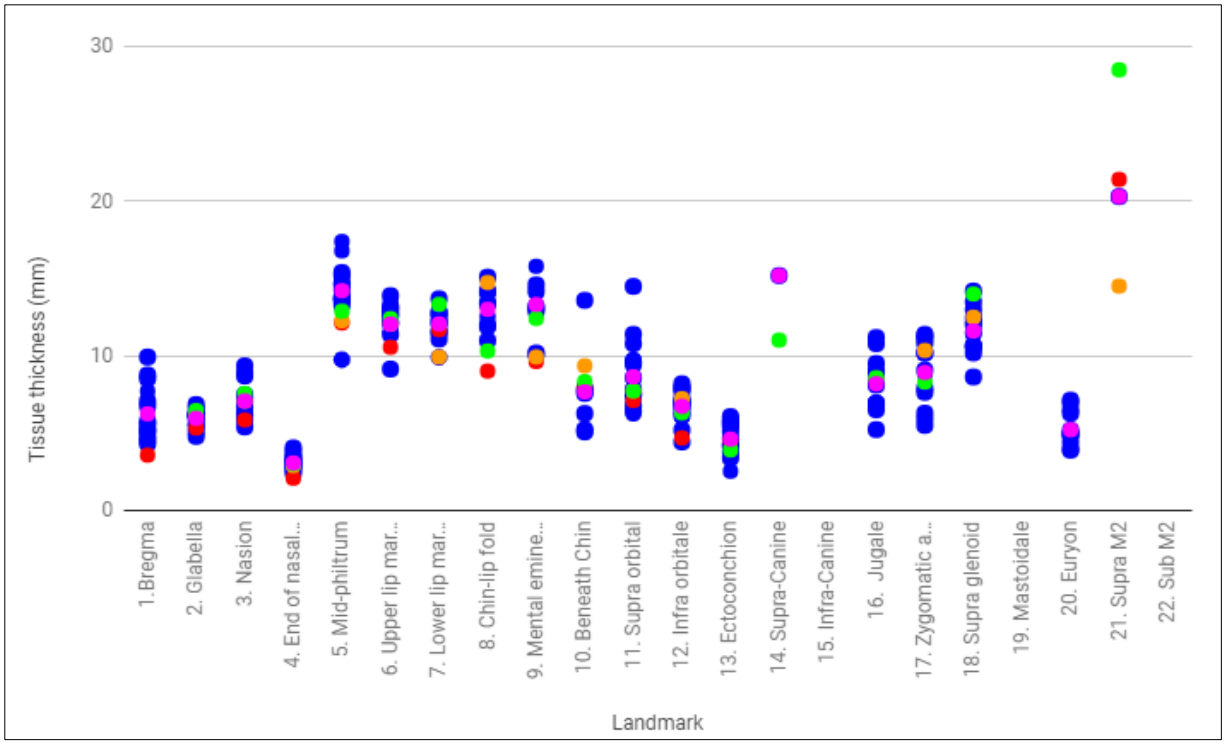


Figure 3.16 – Scatter plot for 30-39 Male population

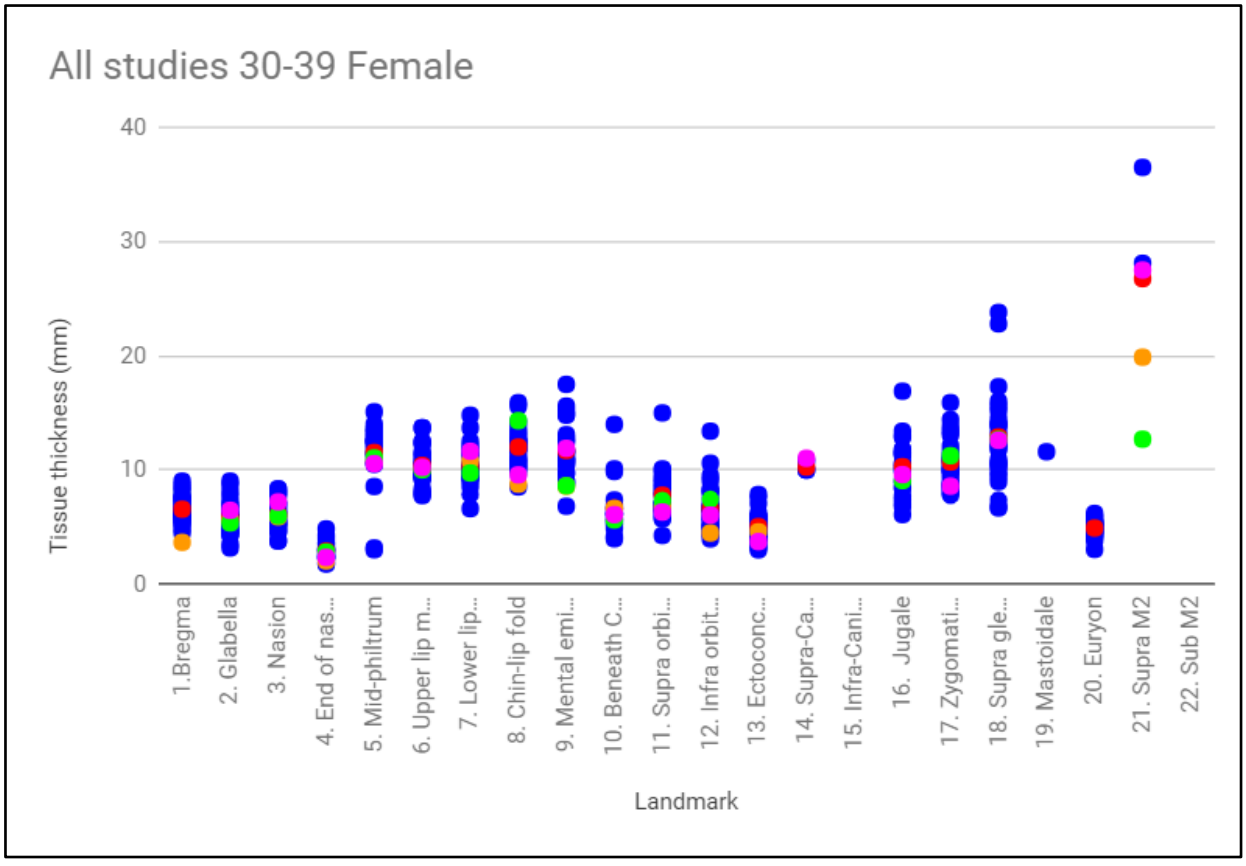


Figure 3.17 – Scatter plot 30-39 Female population

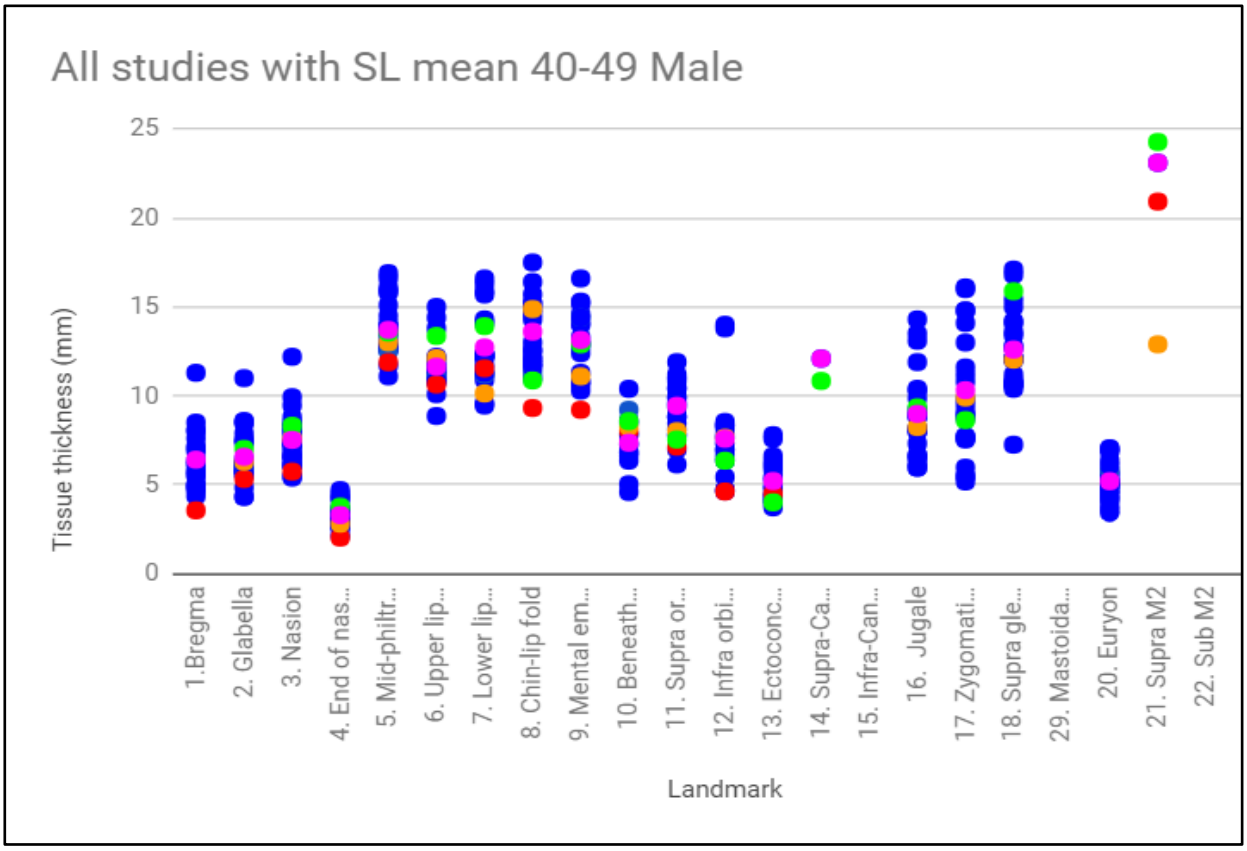


Figure 3.18 – Scatter plot for 40-49 Male population

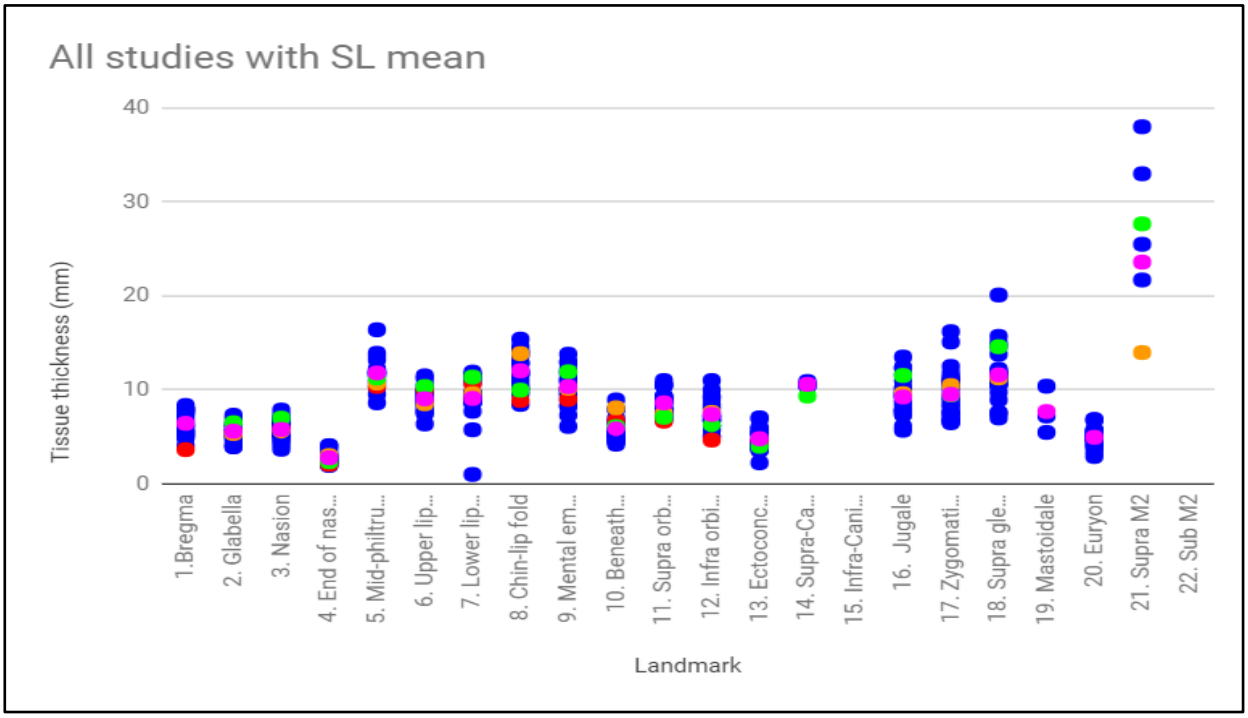


Figure 3.19 – Scatter plot for 40-49 Female population

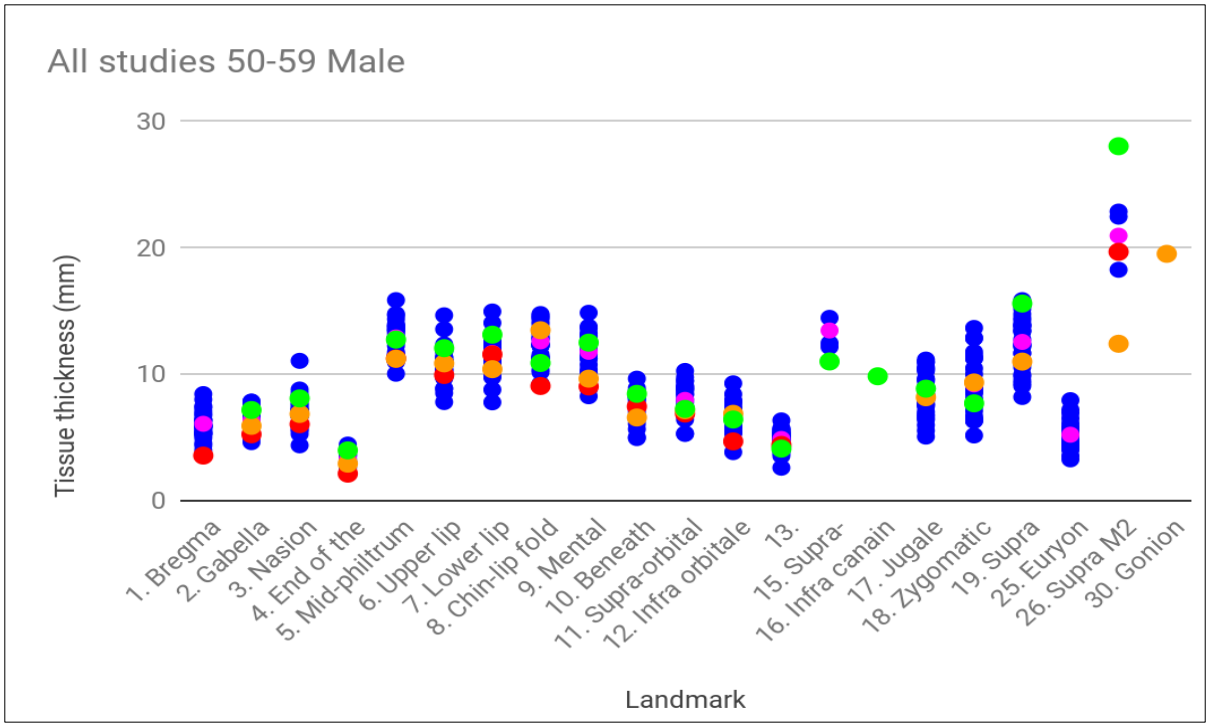
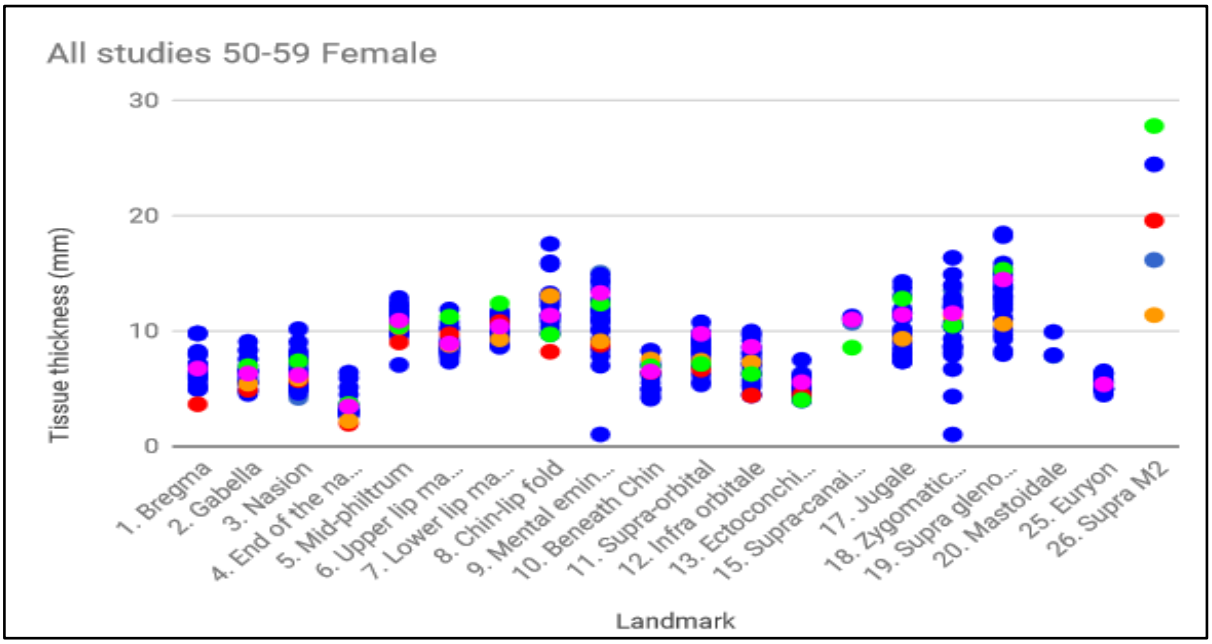


Figure 3.20 – Scatter plot for 50-59 Male population



3.4.3.2. Graphical Representation of the Comparison between the mean values

In the below representations mean values of foreign studies are plotted against mean values of the Sri Lankan population. MATLAB R2013b was used to plot the below representations.

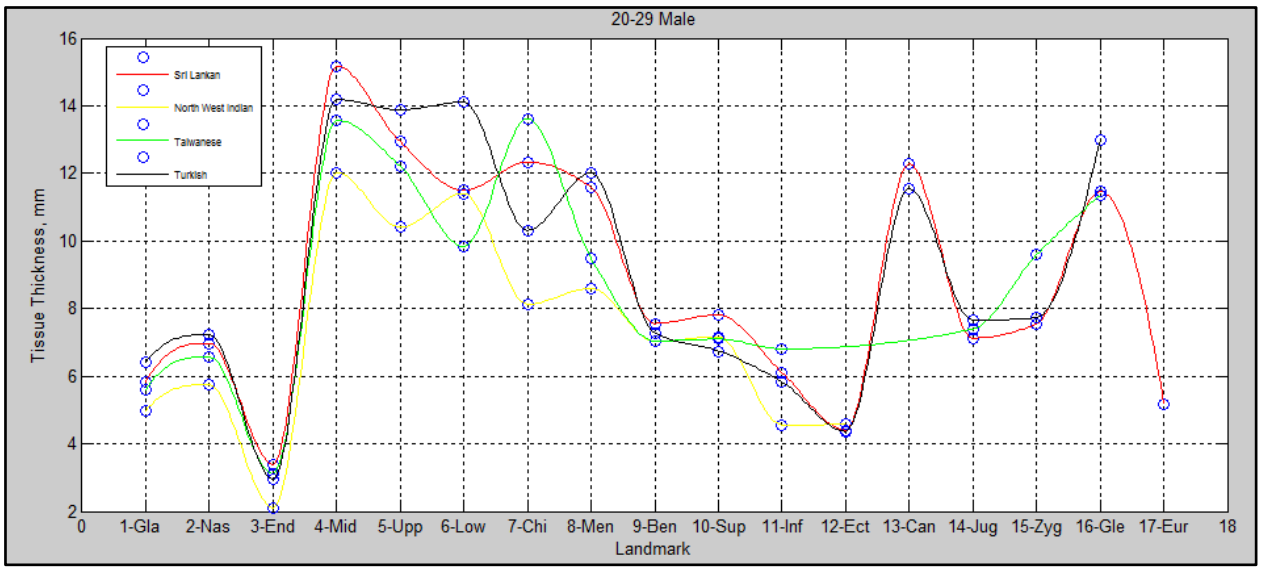


Figure 3.22 - Comparison of mean values- 20-29 males

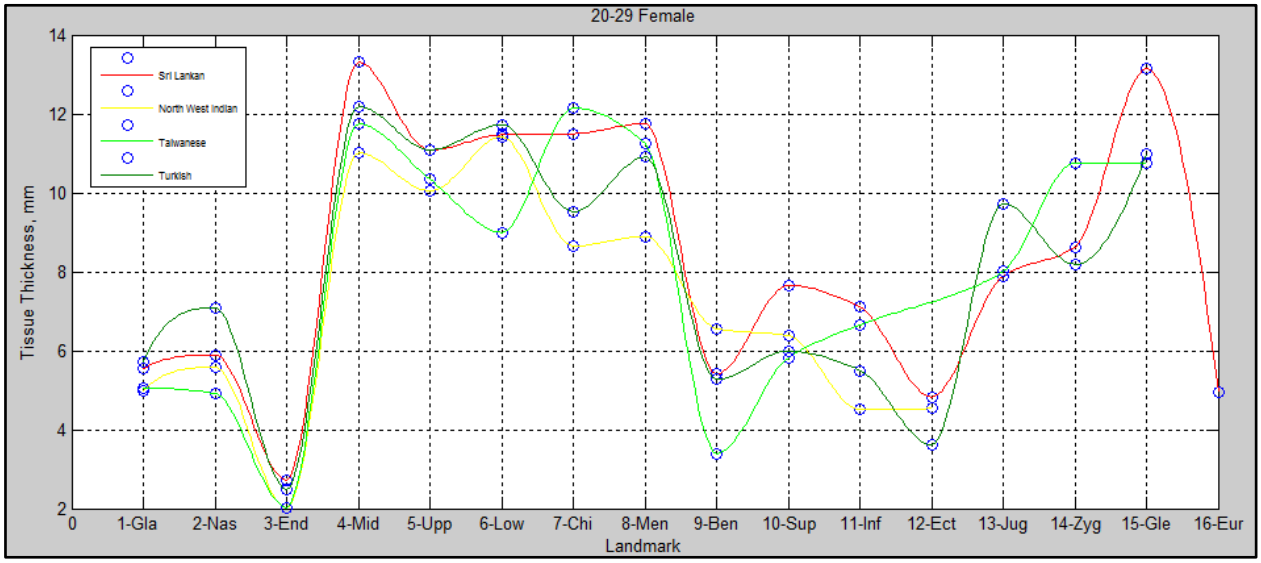


Figure 3.23 - Comparison of mean values- 20-29 females

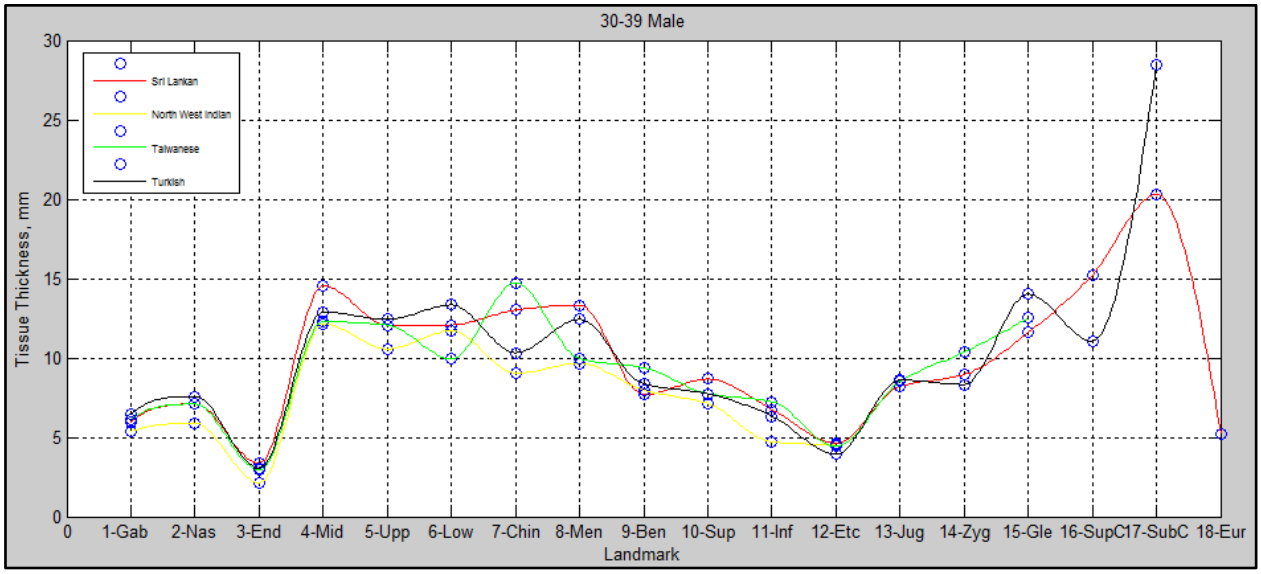


Figure 3.24 - Comparison of mean values- 30-39 males

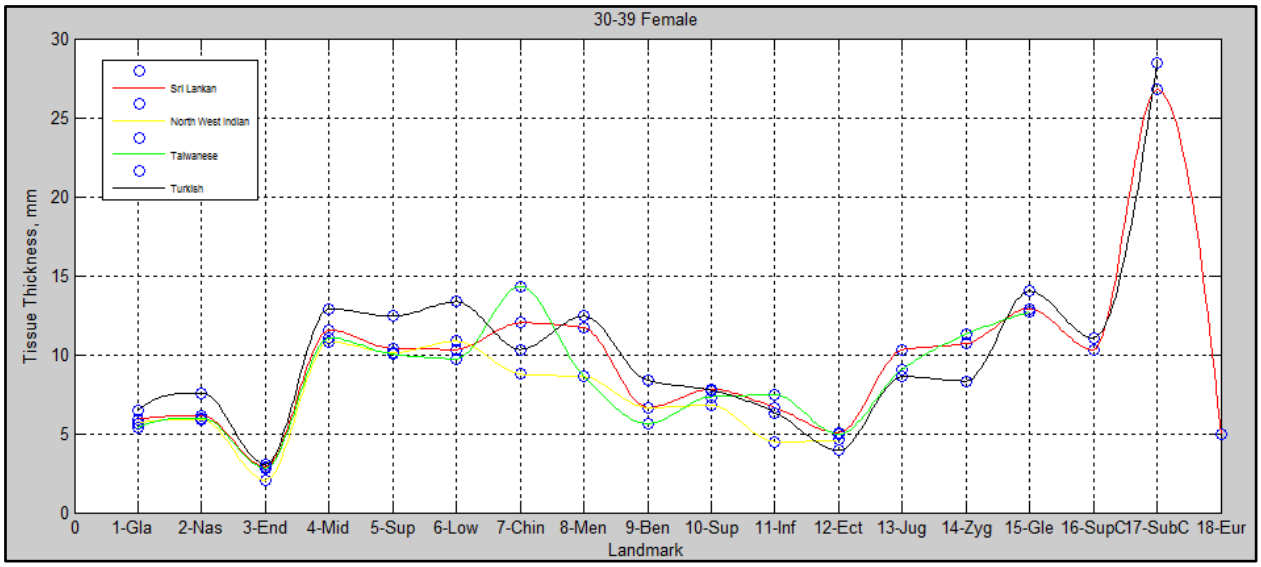


Figure 3.25 - Comparison of mean values- 30-39 females

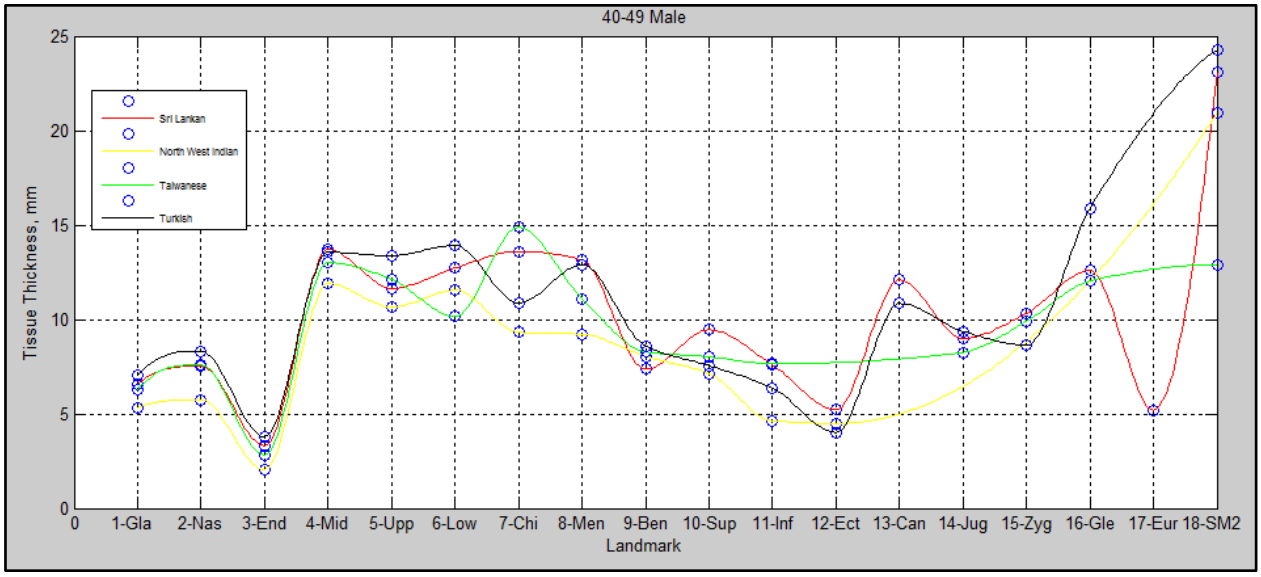


Figure 3.26 - Comparison of mean values- 40-49 males

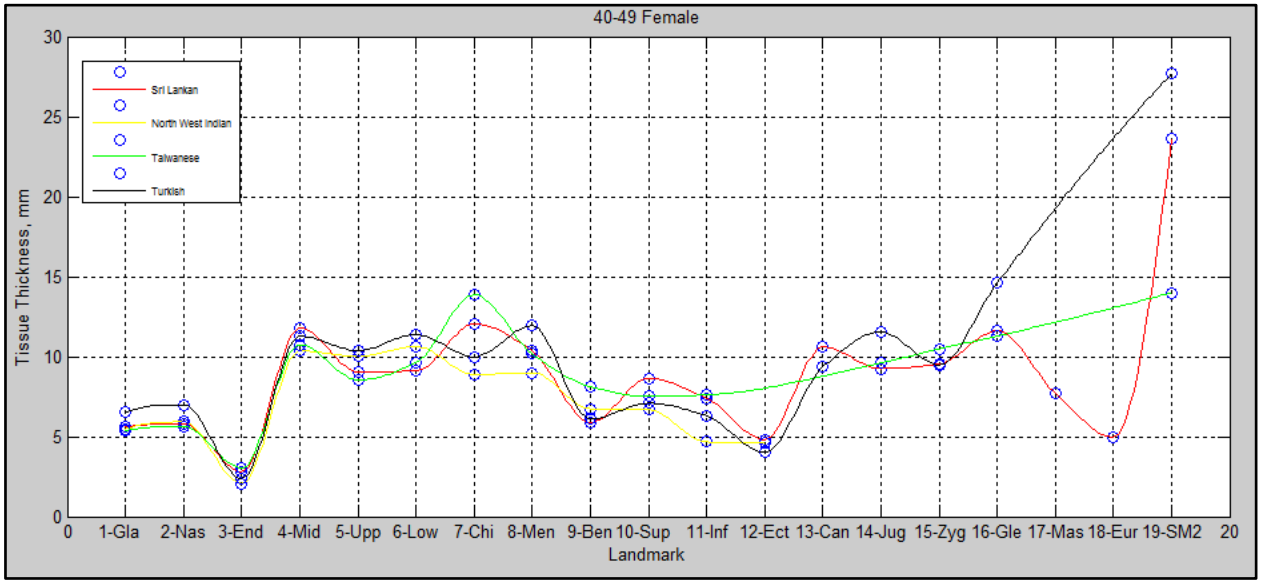


Figure 3.27 - Comparison of mean values- 40-49 females

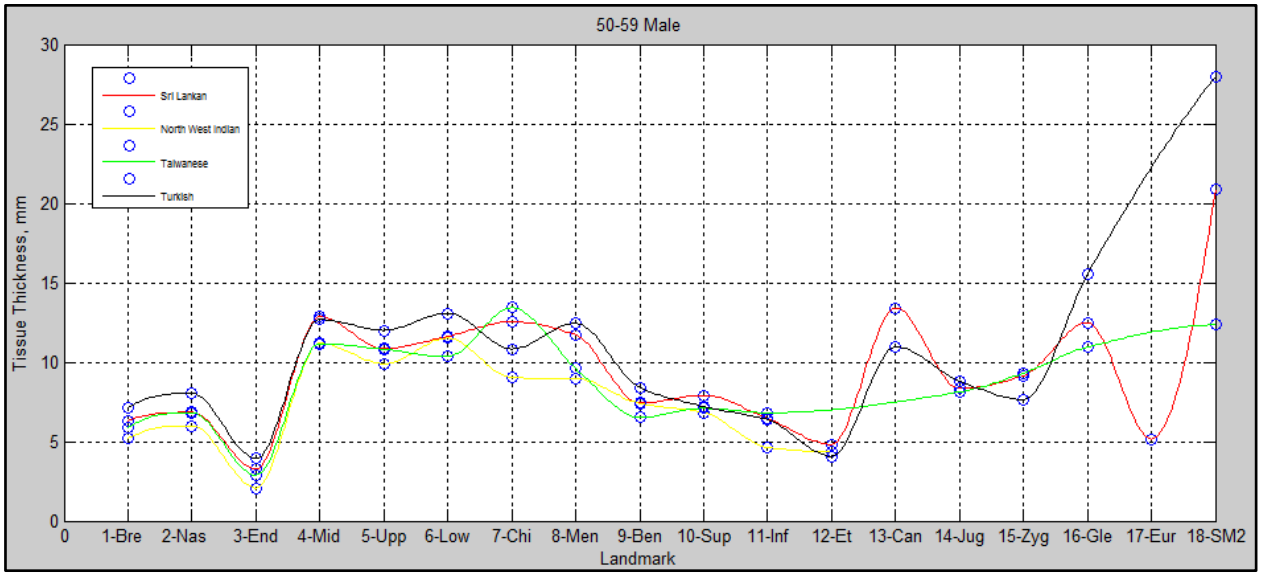


Figure 3.28 - Comparison of mean values- 50-59 males

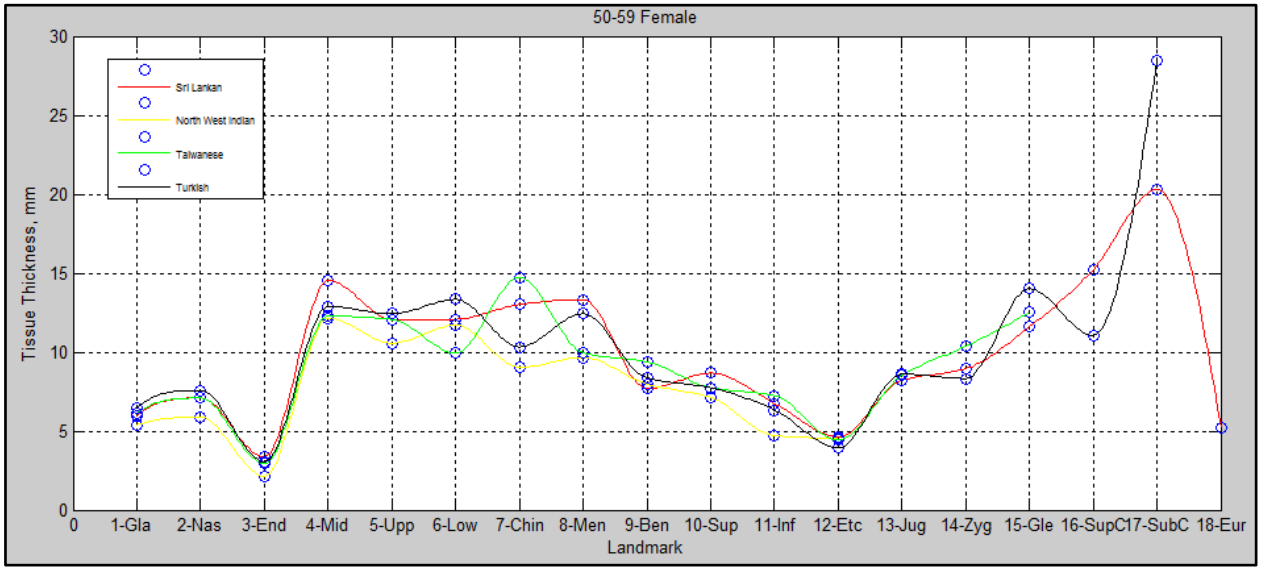


Figure 3.29 - Comparison of mean values- 50-59 Female

3.4.3.3. Statistical Analysis of the Variation of Sri Lankan FSTT Values with Foreign Populations (Z Test Analysis)

Further analysis of the above graphical representations was done using Z test analysis. Z statistic was computed as a result of the Z test analysis using Excel Spreadsheets software. Here, it was assumed that the foreign populations are independent and normally distributed since the relevant literature didn't indicate sufficient information with regard to that or any raw data was not included. The normality of the Sri Lankan sample could be proved from the previously mentioned normality tests.

Following formula was used to calculate the Z statistic [53].

$$Z = \frac{(\bar{X}_1 - \bar{X}_2)}{\sqrt{\sigma_{X_1}^2 + \sigma_{X_2}^2}} \qquad (3)$$

$\bar{x}_1$= Mean value of the Sri Lankan sample

$\bar{x}_{2=}$=Mean value of the foreign sample

σ_{x1}= Standard deviation of the Sri Lankan sample divided by the square root of the number of Sri Lankan samples

σ_{x2}= Standard deviation of the foreign sample divided by the square root of the number of samples of the particular foreign population

Thereafter the significance of the samples was measured based on the corresponding p values (**The result is significant at $p < 0.05$**). The results of the Z test analysis are included in the Results chapter.

3.5. Establishing Learning Methods towards Estimating Missing Data Values

The intention of creating a statistical FSTT model is to predict the Tissue Thickness at a given landmark of any unknown case. Since raw data for foreign studies were not available statistical modeling from interpolation with foreign data was not performed Instead, interpolation of missing values from consecutive age ranges of which the landmarks belong to the same principal component were performed.

Required statistical training in applying statistical analysis and learning methods was obtained from Department of Statistics University of Colombo.

3.5.1. Dimensionality Reduction using Principal Component Analysis (PCA) and Factor Analysis (FA)

Building a statistical model from 23 landmarks is a sophisticated process as the number of variables is comparatively high. Therefore, initially to reduce the dimensionality of the variables Principal Component was performed and number of components was found. Using Factor Analysis the landmarks for each component were determined. Though 22 landmarks were selected, the significant sample to apply Principal Component Analysis and Factor Analysis was available only in 17 landmarks. Due to this reason, the analysis was done only for those 17 landmarks namely Bregma, Glabella, Nasion, End of nasal bone, Mid philtrum, Upper lip, Lower lip, Chin lip, Mental eminence, Beneath chin, Supra orbital, Infra orbital, Ectoconchion, Jugale, Zygomatic arch, Supraglenoid and Euryon.

This analysis was performed using R statistical software and Minitab 18 statistical software for male and female populations. 40-49 and 50-59 age ranges were selected to apply factor analysis. Specifically these age ranges are selected as they contain data sample more than 30.

After reading and printing the dataset to the R statistical software in order to determine the number of factors, Principal Component Analysis is performed using ‘princom’ function. Then the scree plot is used to identify the components/factors which explain the most of variability in the data. Then the Factor Analysis is applied to the identified components/factors using ‘factanal’ function with the ‘varimax’ rotation type. The factor loadings are sorted and landmarks for each factor are identified.

3.5.2. Regression Tree Analysis for Missing Value Estimation

Mean FSTT values calculated for each landmark only provides a generalized FSTT value for all the cases within a certain age group. However, in order to have a much precise measurement for a particular case when a set of possible guesses of FSTT values of landmarks are on hand (e.g - When constructing a deformed skin of a person having burn injuries) regression tree analysis gives a more reasonable set of FSTT values.

Regression tree is a kind of decision tree which is one of the predictive modeling approaches used in statistics, data mining and machine learning where the target variable can take continuous values [55]. A regression tree is a tree-structured predictor which uses a set of (prediction) rules that splits a data set into mutually exhaustive (more homogenous) and non-overlapping subsets (nodes). We can classify the tree nodes into non-terminal nodes (nodes are successively split), and terminal nodes (no further sub-separable). In general, a node splitting into two new nodes is called parent node, while the descending (or generated) nodes are called child nodes. Each terminal node of the tree can be viewed as an imputation cell for the response variable Y. In following Figure shaded area represents all the nodes included in one branch.

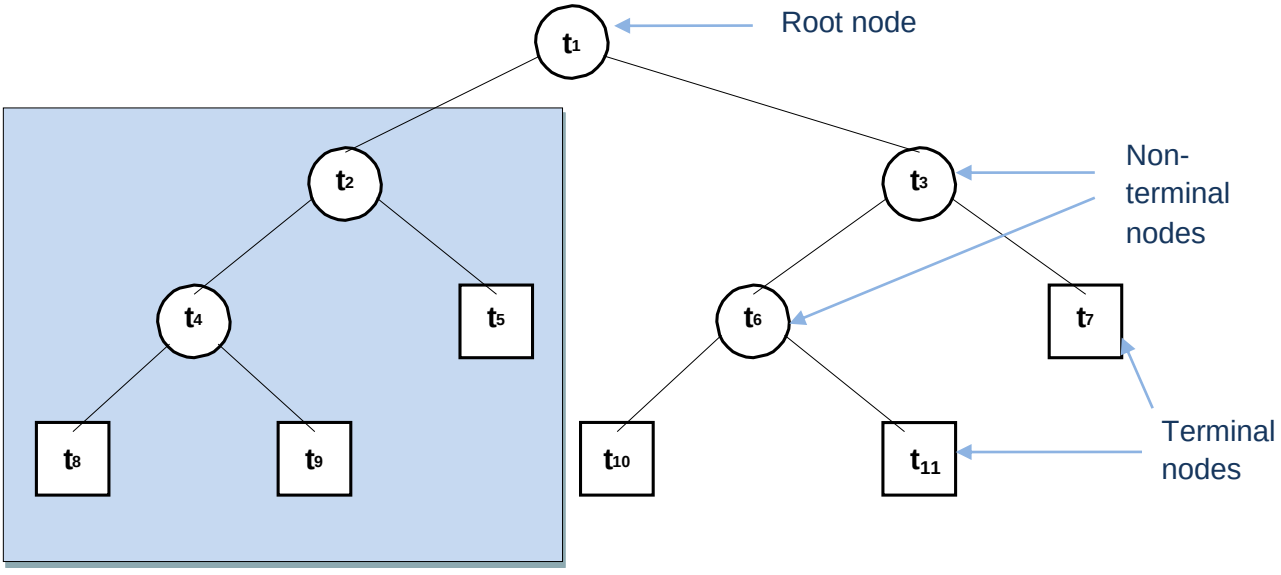


Figure 3.30 – Structure of the Regression Tree

Here the tree-growing process is based on a split mechanism that recursively splits the sample into two subsets characterised by increasing internal homogeneity with respect to the target variable values. In other words, for each node the tree-growing algorithm chooses the partition of data generating nodes “purer” than their parents. In general, this process stops when the lowest

impurity level is reached (the limit case occurs when a generated node is “pure”) or when some stopping rules are met. These rules are generally settled by the analyst and relate to the maximum tree depth (i.e. the level reached by successive splitting starting from the root node), the minimum number of units in (parent and child) nodes, or the threshold for the minimum change in impurity provided by new splits [61]. Similar kind of missing value imputation using regression trees was done by Yuka Higashijima et.al in their research work to impute missing sensor values [56].

With the factor loadings computed previously using R and Minitab 18 software , regression trees were generated to predict FSTT at each landmark using R x64 3.4.1. Rpart (Recursive Partitioning and Regression Trees) and rpart.plot (to plot the regression tree) libraries were used. The result of the regression trees drawn for the factor one of the 40-49 age range and factor two of the 50-59 age range are shown in the section 4.8 Results of the regression tree. See Appendix B for the code written using R to plot the regression tree.

3.5.3. Random Forest Analysis for Missing Value Estimation

In order to evaluate the applicability of random forest regression for the imputation of FSTT values, the same data set used for the regression tree analysis was used as the training sample and testing sample. Random forest operates by constructing a multitude of de-correlated trees, and then averaging them.

Regression trees are known to be unstable as small change in the training data set drastically changing the model. However the training algorithm for random forest applies the general technique of bootstrap aggregation or bagging to tree learners, which resulting on a very stable model. In random forest, it simply estimates the desired Regression Tree on many bootstrap samples (re-sample the data many times with replacement and re-estimate the model) and make the final prediction as the average of the predictions across the trees. [33]

Same as in the regression trees, the variables to apply random forest was selected based on the factor loadings computed earlier. Then the random forest regression was applied to a data set with 40-49 and 50-59 age groups to impute the missing values. Accordingly random forest was performed for the factor with five landmarks - Infra Orbital, Ectoconchion, Jugale, Zygomatic Arch and Supra Glenoid. Supra Glenoid was considered as the target variable of the interpolation and

others were taken as the covariates together with the age which effect on the tissue thickness values of Supra Glenoid.

In order to interpret which variables are more relevant in the Random Forest, importance measures for each variable was calculated. For this %IncMSE (Percentage Increment of Mean Squared Error) and IncNodePurity (Percentage Increment of Node Purity) were used (Table 4.23).The most suitable number of trees for the random forest model was selected by detecting the point where model error decreases and percentage variance increases.

After getting the set of predicted values for the landmark Supra Glenoid by applying random forest, in order to evaluate the accuracy of predictions, previously mentioned Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE) were calculated by comparing actual and imputed data. Also the Mean Absolute Percentage Error (MAPE) was calculated in order to measure the size of the error in percentage terms.

Performance of the regression tree analysis and the random forest regression were compared for the prediction of missing FSTT values of this study using MAE, RMSE and MAPE calculated.

3.6. Accuracy Validation

After developing the tissue thickness database the results were validated by reconstruction of a new case. This new case was constructed based on a known skull (a male aged 41 years). In this process 3D model of the known skull (age and sex known) was generated through 3D scanning [42]. Then the corresponding landmarks used to create the tissue thickness were placed on the skull (In this initial reconstruction landmarks namely Jugale, Zygomatic Arch and Supra Glenoid were considered). Thereafter, digital sculpturing of the face was done by placing the corresponding tissue thickness values in the created database and resultant values of the learning methods developed. For this muscle reconstruction purpose ZBrush™ software (Digital sculpting software) was used.

As it uses a known skull for the reconstruction, the reconstructed case is compared to measure the accuracy of the results. This reconstruction process is done with the help of an expert personnel from University of Colombo School of Computing.

The intention here is to validate the tissue thickness values devised by the learning methods proposed in this research. Here, the authors used the facial reconstruction output validation techniques previously established by this research group to verify whether the outputs devised through the data generated in this research is accurate.

Chapter 4 - Results and Findings

4.1 Introduction

The results of the statistical analysis and learning methods performed in this study are presented under this chapter. For the analysis 218 samples (out of 243 samples including 20 volume MRI samples) were employed since the rest of 25 samples had abnormalities where adequate amount of measurements for the analysis was unable to be gained.

4.2 Results of the Inter-Observer Variability Analysis

As mentioned above, during the data collection process, the tissue thickness of the landmarks were measured by three observers. Before proceeding further, it was important to check the inter-observer variability for the measurement results of the three observers, in order to evaluate the measurement precision (reproducibility). To assess the inter-observer variability, MRI scans from 10 subjects were selected randomly, and the measurements were repeated by the three observers individually. ANOVA F test was performed for this purpose using IBM SPSS Statistics 20 Software. The following results were gained after this analysis.

Landmarks	**Observer 01**			**Observer 02**			**Observer 03**			**ANOVA p value**
	Mean +/- S.D			**Mean +/- S.D**			**Mean +/- S.D**			
	Mean	**S.D**	**Std. Error**	**Mean**	**S.D**	**Std. Error**	**Mean**	**S.D**	**Std. Error**	
Bregma	6.7875	0.4511	0.22555	6.83	1.04243	0.52122	6.93	0.92617	0.46309	0.971
Glabella	7.1917	0.42668	0.17419	7.0883	0.8652	0.35322	6.9883	1.03733	0.42349	0.912
Nasion	6.2633	0.88769	0.3624	6.415	1.16732	0.47656	6.535	0.93921	0.38343	0.897
End of nasal bone	4.8333	0.83392	0.34045	4.5933	1.15419	0.47119	4.3033	1.0275	0.41947	0.67
Mid-philtrum	12.1333	1.85867	0.7588	10.575	1.75052	0.71465	11.55	1.71901	0.70178	0.335
Upper lip margin	10.055	1.42284	0.58087	9.6117	1.41587	0.57803	10.74	2.04817	0.83616	0.509

Lower lip margin	12.0517	1.4893	0.608	12.05	1.6171	0.66018	10.8117	1.19232	0.48676	0.261
Chin-lip fold	11.62	2.09876	0.85682	12.0567	2.0498	0.83683	13	1.75385	0.71601	0.482
Mental eminence	13.1	2.91719	1.30461	12.9	2.88357	1.28957	13.76	2.86409	1.28086	0.887
Beneath chin	5.508	3.87106	1.73119	5.876	4.10352	1.83515	5.758	4.04968	1.81107	0.989
Supra orbital	9.8717	1.05876	0.43224	9.7033	1.84012	0.75122	9.2067	1.54554	0.63097	0.737
Infra orbital	9.035	1.04186	0.42534	9.7917	1.33056	0.5432	9.3833	1.20409	0.49157	0.562
Ectoconchion	5.392	0.7111	0.31802	5.528	1.95715	0.87526	5.664	1.37298	0.61402	0.957
Supra canine	12	1.66433	0.9609	11.9667	1.43643	0.82932	12	1.92873	1.11355	1
Jugale	11.5167	1.17884	0.48126	11.3033	1.69712	0.69285	12.5833	1.37756	0.56239	0.284
Zygomatic arch	11.855	2.45551	1.00246	12.0867	2.89862	1.18336	12.9183	3.06164	1.24991	0.792
Supra glenoid	15.5667	4.62284	1.88727	14.9667	3.86919	1.57959	16.8833	4.32084	1.76398	0.735
Euryon	6.0017	0.7295	0.29789	5.7267	0.72737	0.29695	5.515	0.68225	0.27853	0.511

Table 4.1 – Inter-observer variability analysis

S.D- Standard Deviation

Std.error- Standard Error

Results indicate that for all the measurements the level of significance (p value) corresponding to ANOVA F test was greater than 0.05. Hence we could conclude that the difference between the mean values of the 3 observers were minimal for all the landmarks. This implies that all measurements were reproducible and can be continued with the analysis without a problem.

4.3 Results of Basic Descriptive Statistics

General descriptive analyses such as Mean, SD (Standard Deviation) and Range were determined for each anatomical landmark, and average soft tissue thicknesses were calculated considering the gender and the age groups of the individuals.

Below tables represent the tissue depth Mean, Standard Deviation, Range for males and females calculated for the nearest 0.01mm: (a) between 20 and 29 years, (b) between 30 and 39 years, (c) between 40 and 49 years, (d) between 50 and 59 years age groups

(a)

Landmark	**Mean**	**SD**	**Min**	**Max**	**Range**
Bregma	6.25	1.08	4.56	8.01	3.45
Glabella	5.83	0.78	4.74	6.82	2.08
Nasion	6.97	1.52	5.04	11	5.96
End of nasal bone	3.39	0.43	2.47	3.92	1.45
Mid philtrum	15.17	1.98	12.7	17.75	5.05
Upper lip margin	12.92	1.18	11.2	15.2	4
Lower lip margin	11.49	1.55	8.83	14.6	5.77
Chin-lip fold	12.34	1.65	9.81	15.1	5.29
Mental eminence	11.60	2.73	7.05	15.1	8.05
Beneath Chin	7.56	2.50	4.46	11.3	6.84
Supra orbital	7.82	1.16	5.32	9.24	3.92
Infra orbital	6.09	0.92	4.94	7.93	2.99
Ectoconchion	4.41	0.42	3.69	5.23	1.54
Jugale	7.13	1.06	6.14	9.64	3.5
Zygomatic arch	7.54	1.62	5.45	10.9	5.45
Supra glenoid	11.47	2.58	7.21	15.5	8.29
Mastoidale	7.20	1.24	6.32	8.085	1.765
Euryon	5.18	0.75	4.05	6.52	2.47

Table 4.2 – Basic descriptive statistics for 20-29 age group- Male population

Landmark	**Mean**	**SD**	**Min**	**Max**	**Range**
Bregma	7.07	1.04	5.94	10	4.06
Glabella	5.54	0.78	4.61	7.73	3.12
Nasion	5.88	0.98	4.31	7.28	2.97
End of nasal bone	2.70	0.27	2.34	3.08	0.74

Mid philtrum	13.30	1.43	10.7	15.4	4.7
Upper lip margin	11.08	1.01	8.54	12.1	3.56
Lower lip margin	11.46	1.24	9.03	13.2	4.17
Chin-lip fold	11.49	2.08	8.45	15.2	6.75
Mental eminence	11.75	2.38	7.23	14.9	7.67
Beneath Chin	5.41	0.99	3.75	6.91	3.16
Supra orbital	7.66	1.03	5.62	8.97	3.35
Infra orbital	7.11	1.62	4.9	9.3	4.4
Ectoconchion	4.83	1.15	2.46	6.49	4.03
Jugale	7.88	4.47	1.24	18.1	16.86
Zygomatic arch	8.63	4.84	4.55	20.3	15.75
Supra glenoid	13.14	3.68	8.45	21	12.55
Mastoidale	4.9	2.01	3.48	7.83	4.35
Euryon	4.95	0.979	3.87	6.92	3.05

Table 4.3 - Basic descriptive statistics for 20-29 age group- Female population

(b)

Landmarks	**Mean**	**SD**	**Max**	**Min**	**Range**
Bregma	6.27	1.77	9.94	4.33	5.61
Glabella	5.97	0.55	6.87	4.81	2.06
Nasion	7.09	1.11	9.37	5.42	3.95
End of nasal bone	3.34	0.51	4.07	2.42	1.65
Mid philtrum	14.54	1.88	17.4	9.77	7.63
Upper lip margin	12.29	1.22	13.9	9.16	4.74
Lower lip margin	12.078	0.96	13.7	9.92	3.78
Chin-lip fold	13.02	1.24	15.1	11	4.1
Mental eminence	13.13	1.80	15.8	10.1	5.7
Beneath Chin	7.68	2.49	13.6	5.1	8.5
Supra orbital	8.67	2.18	14.5	6.26	8.24

Infra orbital	6.75	1.00	8.21	4.45	3.76
Ectoconchion	4.64	1.06	6.09	2.56	3.53
Jugale	8.21	1.71	11.2	5.25	5.95
Zygomatic arch	8.94	2.10	11.4	5.52	5.88
Supra glenoid	11.62	1.50	14.2	8.65	5.55
Euryon	5.24	1.08	7.15	3.92	3.23

Table 4.4 - Basic descriptive statistics for 30-39 age group- Male population

Landmark	**Mean**	**SD**	**Max**	**Min**	**Range**
Bregma	6.56	1.28	9.03	4.5	4.53
Glabella	5.90	1.50	9.03	3.18	5.85
Nasion	6.12	1.36	8.35	3.78	4.57
End of nasal bone	2.89	0.75	4.85	1.77	3.08
Mid-philtrum	11.54	2.81	15.1	3.02	12.08
Upper lip margin	10.38	1.67	13.7	7.76	5.94
Lower lip margin	10.33	1.78	14.8	6.62	8.18
Chin-lip fold	12.01	1.70	15.9	8.52	7.38
Mental eminence	11.70	2.46	15.6	6.83	8.77
Beneath Chin	6.64	2.31	14	3.98	10.02
Supra orbital	7.80	2.057	10.1	4.27	5.83
Infra orbital	6.63	2.10	13.4	3.97	9.43
Ectoconchion	5.05	1.28	7.86	3.01	4.85
Jugale	10.27	2.43	16.9	6.1	10.8
Zygomatic arch	10.65	2.14	15.9	7.78	8.12
Supra glenoid	12.85	4.22	23.8	6.68	17.12
Euryon	4.92	0.70	6.2	3.05	3.15

Table 4.5 - Basic descriptive statistics for 30-39 age group- Female population

(c)

Landmark	Mean	SD	Min	Max	Range
Bregma	6.41	1.65	4.38	11.3	6.92
Glabella	6.58	1.53	4.33	11	6.67
Nasion	7.53	1.54	5.41	12.2	6.79
End of nasal bone	3.30	0.66	2.16	4.71	2.55
Mid-philtrum	13.72	1.53	11.1	16.6	5.5
Upper lip margin	11.64	1.48	8.87	15	6.13
Lower lip margin	12.72	2.16	9.46	16.6	7.14
Chin-lip fold	13.61	2.05	11	17.5	6.5
Mental eminence	13.15	1.84	10.3	16.6	6.3
Beneath Chin	7.37	1.54	4.6	10.4	5.8
Supra orbital	9.45	1.40	6.15	11.90	5.75
Infra orbital	7.59	2.27	4.64	14	9.36
Ectoconchion	5.21	1.11	3.74	7.8	4.06
Jugale	8.99	2.45	5.56	14.3	8.74
Zygomatic arch	10.32	3.51	5.19	16.1	10.91
Supra glenoid	12.60	2.24	7.26	17.1	9.84
Euryon	5.12	0.99	3.41	7.06	3.65

Table 4.6 - Basic descriptive statistics for 40-49 age group- Male population

Landmark	Mean	SD	Min	Max	Range
Bregma	6.44	1.18	4.05	8.35	4.3
Glabella	5.61	0.87	3.96	7.31	3.35
Nasion	5.8	0.99	3.69	7.86	4.17
End of nasal bone	2.78	0.54	1.97	4.07	2.1
Mid philtrum	11.81	1.56	8.63	16.4	7.77
Upper lip margin	9.06	1.26	6.38	11.5	5.12
Lower lip margin	9.09	2.32	1.01	11.9	10.89
Chin-lip fold	12.04	1.79	8.46	15.4	6.94
Mental eminence	10.35	1.92	6.12	13.8	7.68
Beneath Chin	5.86	1.30	4.23	8.94	4.71
Supra orbital	8.63	1.17	6.81	11	4.19

Infra orbital	7.40	1.51	5.02	11	5.98
Ectoconchion	4.81	1.14	2.25	7.03	4.78
Supra-Canine	10.6	0.26	10.4	10.9	0.5
Jugale	9.25	1.94	5.71	13.5	7.79
Zygomatic arch	9.53	2.60	6.51	16.2	9.69
Supra glenoid	11.61	2.82	7.02	20.1	13.08
Mastoidale	7.70	2.49	5.48	10.4	4.92
Euryon	4.95	0.91	2.92	6.86	3.94
Supra M2	23.6	2.68	21.7	38	16.3

Table 4.7 - Basic descriptive statistics for 40-49 age group- Female population

(d)

Landmark	**Mean**	**SD**	**Min**	**Max**	**Range**
Bregma	6.02	0.97	4.31	8.37	4.06
Glabella	6.31	0.90	4.57	7.78	3.21
Nasion	6.83	1.40	3.78	11	7.22
End of nasal bone	3.26	0.47	2.46	4.38	1.92
Mid philtrum	12.85	1.35	9.98	15.8	5.82
Upper lip margin	10.85	1.55	7.74	14.6	6.86
Lower lip margin	11.62	1.56	7.72	14.9	7.18
Chin-lip fold	12.54	1.64	9.19	15.57	6.37
Mental eminence	11.71	1.67	8.2	14.8	6.6
Beneath Chin	7.42	1.54	4.89	9.64	4.75
Supra orbital	7.91	1.33	5.22	10.7	5.48
Infra orbital	6.44	1.10	3.78	9.22	5.44
Ectoconchion	4.82	0.76	2.55	6.29	3.74
Supra-Canine	13.4	1.41	12.4	14.4	2
Jugale	8.34	1.78	5.01	11.1	6.09
Zygomatic arch	9.14	2.21	5.1	13.7	8.6
Supra glenoid	12.49	2.06	8.14	15.8	7.66
Euryon	5.15	1.11	3.21	7.89	4.68
Supra M2	20.89	2.34	18.2	22.4	4.2

Table 4.8 - Basic descriptive statistics for 50-59 age group- Male population

Landmark	Female	SD	Min	Max	Range
Bregma	6.78	1.34	4.99	9.83	4.84
Glabella	6.35	1.19	4.58	9.11	4.53
Nasion	6.22	1.47	4.24	10.2	5.96
End of nasal bone	3.49	0.91	2.63	6.44	3.81
Mid philtrum	10.93	1.39	7.09	13.1	6.01
Upper lip margin	8.94	0.99	7.38	10.8	3.42
Lower lip margin	10.42	1.08	8.66	12.53	3.87
Chin-lip fold	11.94	1.45	9.76	16	6.24
Mental eminence	11.37	3.34	1.06	15.1	14.04
Beneath Chin	5.96	1.32	4.16	8.32	4.16
Supra orbital	8.36	1.38	5.41	10.79	5.383
Infra orbital	7.48	1.38	5.41	10.79	5.38
Ectoconchion	5.21	0.83	4.02	7.53	3.51
Supra-Canine	11.03	0.37	10.76	11.3	0.53
Jugale	10.27	2.41	7.43	15.9	8.47
Zygomatic arch	11.03	3.03	4.36	16.4	12.04
Supra glenoid	12.97	2.82	8.04	18.5	10.46
Euryon	5.41	0.60	4.52	6.54	2.02

Table 4.9 - Basic descriptive statistics for 50-59 age group- Female population

4.4 Results of the Normality Test

By performing normality tests namely Jarque-Bera test, Anderson - Darling test, Shapiro-Wilk's test and Q-Q plot using the software R x64 3.4.1, we were able to prove that the Sri Lankan data sample is normally distributed. These tests reject the hypothesis of normality when the p value is less than or equal to 0.05. Below table shows the results of the normality tests (Table 4.10).

Age Range	Gender	Landmark	Shapiro-Wilk	Anderson - Darling	Jarque-Bera
20-29	Male	Bregma	0.8484	0.8973	0.7516
20-29	Male	Glabella	0.1148	0.184	0.563
20-29	Male	Nasion	0.05505	0.0976	0.09401
20-29	Male	End of Nasal bone	0.4047	0.5063	0.6247
20-29	Male	Mid-Philtrum	0.1441	0.2278	0.5565
20-29	Male	Upper Lip Margin	0.7391	0.5829	0.7784
20-29	Male	Lower Lip Margin	0.9649	0.8283	0.9817
20-29	Male	Chin Lip fold	0.8829	0.8694	0.7899
20-29	Male	Mental eminence	0.592	0.5903	0.6739
20-29	Male	Beneath chin	0.865	0.812	0.817
20-29	Male	Supra Orbital	0.5393	0.5963	0.6356
20-29	Male	Infra Orbital	0.09817	0.09885	0.4053
20-29	Male	Ectoconchion	0.2702	0.1503	0.4045
20-29	Male	Jugale	0.0276	0.04316	0.1014
20-29	Male	Zygomatic Arch	0.6121	0.5798	0.5753
20-29	Male	Supra Glenoid	0.9554	0.8972	0.8868
20-29	Male	Euryon	0.966	0.9001	0.8844

20-29	Female	Nasion	0.4435	0.4671	0.6574
20-29	Female	End of Nasal Bone	0.1747	0.2995	0.6009
20-29	Female	Mid-philtrum	0.8328	0.8584	0.7699
20-29	Female	Upper Lip Margin	0.781	0.6097	0.8764
20-29	Female	Lower Lip Margin	0.9824	0.9549	0.8375
20-29	Female	Chin Lip Fold	0.7936	0.8243	0.7697
20-29	Female	Mental Eminence	0.6466	0.5821	0.715
20-29	Female	Beneath Chin	0.8002	0.7224	0.7656
20-29	Female	Supra orbital	0.6169	0.6223	0.6505
20-29	Female	Infra orbital	0.3046	0.4666	0.6102
20-29	Female	Ectoconchion	0.467	0.3936	0.8661
20-29	Female	Jugale	0.02633	0.04474	0.146
20-29	Female	Supra Glenoid	0.1935	0.1787	0.3608
20-29	Female	Euryon	0.3387	0.4381	0.5395
30-39	Male	Glabella	0.8567	0.691	0.7581
30-39	Male	Nasion	0.1844	0.174	0.2003
30-39	Male	Mid-philtrum	0.4914	0.683	0.653
30-39	Male	Supra orbital	0.3512	0.362	0.1557
30-39	Male	Jugale	0.4127	0.483	0.5196

30-39	Female	Bregma	0.1068	0.3919	0.1667
30-39	Female	End of nasal bone	0.4138	0.6091	0.2016
30-39	Female	Upper lip margin	0.2732	0.54	0.2143
30-39	Female	Lower lip margin	0.1742	0.3062	0.1359
30-39	Female	Supra orbital	0.1566	0.4607	0.1437
30-39	Female	Ectoconchion	0.5373	0.5983	0.585
30-39	Female	Zygomatic arch	0.8841	0.9015	0.7404
40-49	Male	Bregma	0.03227	0.02446	0.04566
40-49	Male	Euryon	0.6233	0.7457	0.7899
40-49	Male	Glabella	0.05792	0.1268	0.2366
40-49	Male	Infra orbital	0.0003409	0.0001591	0.0237
40-49	Male	Supra orbital	0.8148	0.6107	0.6788
40-49	Male	Zygomatic arch	0.137	0.4784	0.5677
40-49	Female	Bregma	0.2498	0.6005	0.6788
40-49	Female	Chinlip	0.9404	0.8471	0.8657
40-49	Female	Ectoconchion	0.5667	0.947	0.9874
40-49	Female	Euryon	0.6487	0.937	0.9756
40-49	Female	Jugale	0.7661	0.7602	0.7602

40-49	Female	Nasion	0.9825	0.9336	0.8754
40-49	Female	Supra orbital	0.2479	0.564	0.4673
50-59	Male	Bregma	0.7017	0.6705	0.7143
50-59	Male	Chin lip fold	0.5199	0.6747	0.6843
50-59	Male	Glabella	0.3089	0.4753	0.4862
50-59	Male	Infra orbital	0.9939	0.9312	0.9216
50-59	Male	Supra glenoid	0.3311	0.4685	0.5138
50-59	Female	Glabella	0.2968	0.469	0.4387
50-59	Female	Jugale	0.05964	0.3977	0.3744
50-59	Female	Supra orbital	0.2021	0.4415	0.4943
50-59	Female	Upper lip	0.06928	0.1789	0.1432

Table 4.10 - Normality test results

(Jarque-Bera test, Anderson - Darling test and Shapiro-Wilk's test)

On the Q-Q plots, data appears as roughly a straight line. Although the ends of the Q-Q plot often start to deviate, it showed a minimal deviation from the straight line. Hence it can be concluded that the data are normally distributed. Below graphs (figure 4.1 - figure 4.4) show Q-Q plot diagrams drawn for Chin lip fold, Zygomatic Arch, Jugale and Supra Orbital landmarks.

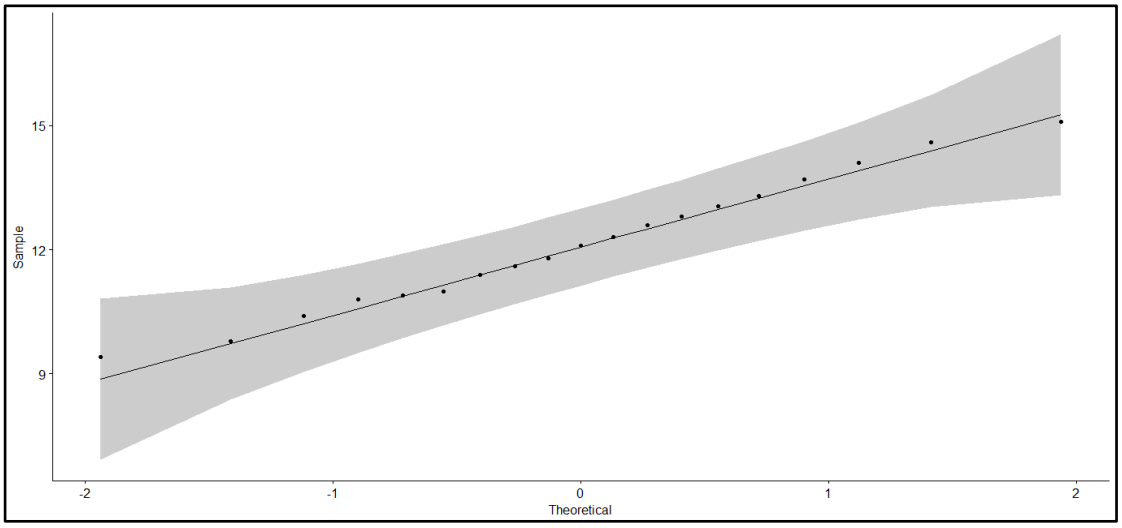


Figure 4.1 - Q-Q plot result for the Landmark Chin-lip fold (Female, 20-29 age range)

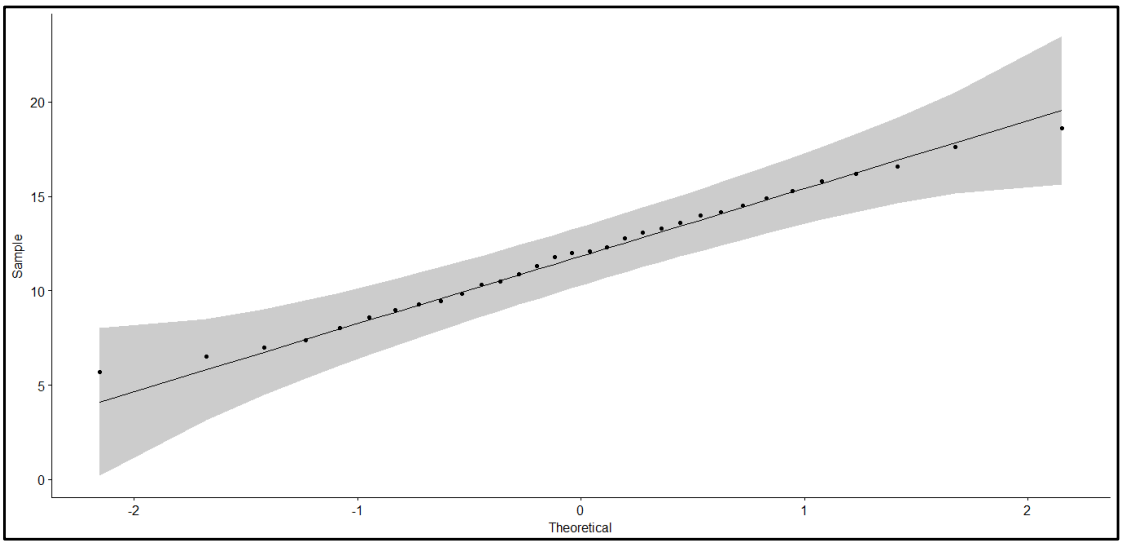


Figure 4.2 - Q-Q plot result for the Landmark Zygomatic arch (Female, 30-39 age range)

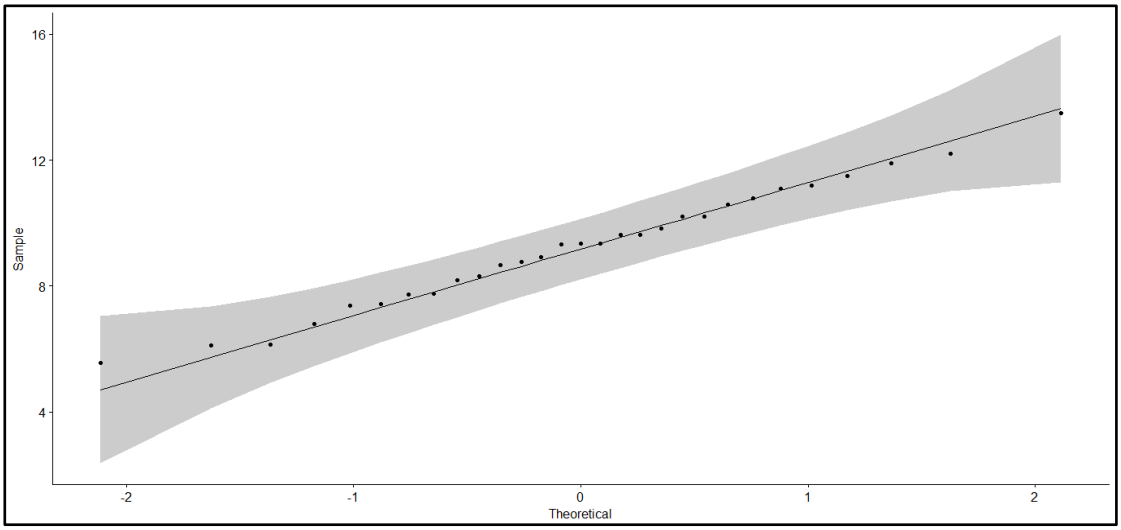


Figure 4.3 - Q-Q plot result for the Landmark Jugale (Female, 40 -49 age range)

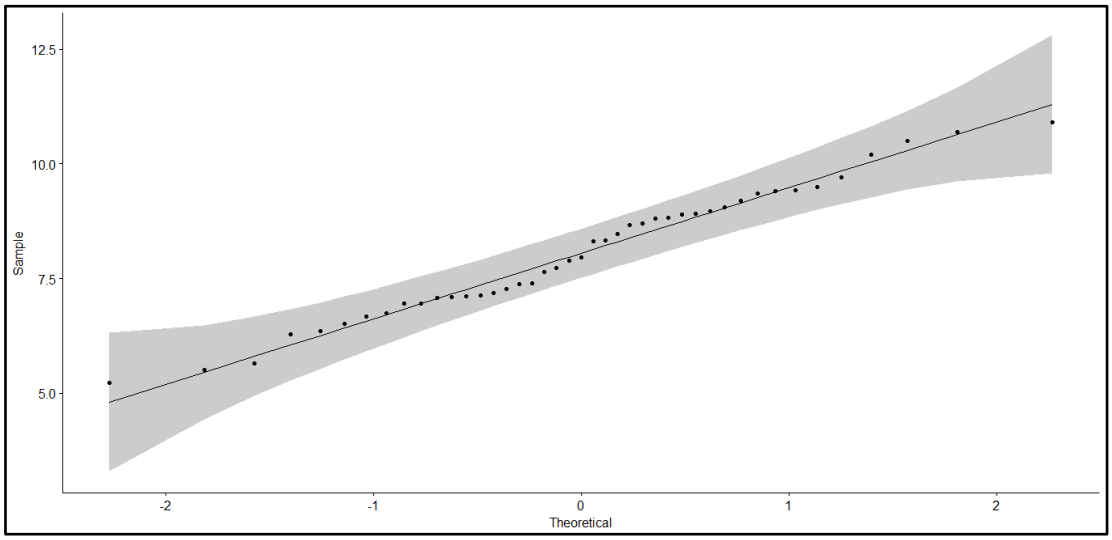


Figure 4.4 - Q-Q plot result for the Landmark Supra Orbital (Male, 50-59 age range)

4.5 Comparison of Sri Lankan Facial Tissue Thickness Values within the gender groups

The below results show the results of Independent T test which was performed to evaluate the significance level ($p<0.05$) of FSTT at each landmark between gender groups of each age category.

T test results for 20-29 age group

Independent Samples Test								
Landmark		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Bregma	Equal variances assumed	.805	.378	-1.895	24	.070	-.769	.406
	Equal variances not assumed			-1.895	23.999	.070	-.769	.406
Glabella	Equal variances assumed	.287	.598	.356	22	.725	.126	.354
	Equal variances not assumed			.355	21.179	.726	.126	.354
Nasion	Equal variances assumed	.017	.897	2.097	22	.048	1.154	.550
	Equal variances not assumed			2.044	18.134	.056	1.154	.565
End of nasal bone	Equal variances assumed	4.183	.054	2.928	21	.008	.705	.241
	Equal variances not assumed			2.876	17.065	.010	.705	.245

Mid philtrum	Equal variances assumed	4.542	.044	3.084	22	.005	2.119	.687
	Equal variances not assumed			2.984	17.009	.008	2.119	.710
Upper lip margin	Equal variances assumed	.879	.359	3.056	22	.006	1.538	.503
	Equal variances not assumed			3.107	21.992	.005	1.538	.495
Lower lip margin	Equal variances assumed	.197	.661	.435	22	.668	.250	.575
	Equal variances not assumed			.435	20.847	.668	.250	.575
Chin-lip fold	Equal variances assumed	2.008	.170	1.306	22	.205	.979	.749
	Equal variances not assumed			1.349	21.145	.192	.979	.726
Mental eminence	Equal variances assumed	.116	.738	.340	16	.738	.400	1.176
	Equal variances not assumed			.336	14.365	.742	.400	1.190
Beneath Chin	Equal variances assumed	9.401	.008	2.380	15	.031	1.970	.828

	Equal variances not assumed			1.859	5.756	.114	1.970	1.059
Supra orbital	Equal variances assumed	1.041	.318	-.165	24	.870	-.077	.466
	Equal variances not assumed			-.165	22.636	.870	-.077	.466
Infra orbital	Equal variances assumed	4.540	.044	-1.215	24	.236	-.615	.506
	Equal variances not assumed			-1.215	20.468	.238	-.615	.506
Ectoconchion	Equal variances assumed	3.378	.078	-1.256	24	.221	-.462	.368
	Equal variances not assumed			-1.256	17.783	.225	-.462	.368
Jugale	Equal variances assumed	11.395	.003	-1.520	21	.143	-1.746	1.149
	Equal variances not assumed			-1.353	10.162	.205	-1.746	1.291
Zygomatic Arch	Equal variances assumed	6.883	.016	-1.398	21	.177	-1.908	1.365
	Equal variances not assumed			-1.254	10.687	.236	-1.908	1.521

Supra Glenoid	Equal variances assumed	.610	.443	-1.225	21	.234	-1.585	1.294
	Equal variances not assumed			-1.170	15.486	.260	-1.585	1.355
Euryon	Equal variances assumed	.228	.637	.192	23	.849	.077	.400
	Equal variances not assumed			.192	22.328	.850	.077	.401

Table 4.11- Results of T test 20-29 age group

T test result for 30-39 age group

Independent Samples Test								
Landmarks		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Bregma	Equal variances assumed	5.304	.027	-.799	39	.429	-.36613	.45819
	Equal variances not assumed			-.716	21.133	.482	-.36613	.51123

Glabella	Equal variances assumed	9.230	.004	-.086	39	.932	-.03233	.37373
	Equal variances not assumed			-.102	33.627	.919	-.03233	.31620
Nasion	Equal variances assumed	1.608	.212	2.225	39	.032	.87888	.39495
	Equal variances not assumed			2.307	35.767	.027	.87888	.38099
End of nasal bone	Equal variances assumed	2.284	.140	.627	35	.534	.12836	.20461
	Equal variances not assumed			.665	34.089	.510	.12836	.19295
Mid-philtrum	Equal variances assumed	1.016	.320	3.475	39	.001	2.79338	.80383
	Equal variances not assumed			3.933	38.751	.000	2.79338	.71029
Upper lip margin	Equal variances assumed	1.938	.172	3.654	36	.001	1.91572	.52432

	Equal variances not assumed			4.029	31.658	.000	1.91572	.47542
Lower lip margin	Equal variances assumed	2.755	.106	3.274	35	.002	1.74638	.53347
	Equal variances not assumed			3.870	34.986	.000	1.74638	.45128
Chin-lip fold	Equal variances assumed	.858	.361	1.836	35	.075	1.04031	.56657
	Equal variances not assumed			2.122	26.858	.043	1.04031	.49021
Mental eminence	Equal variances assumed	1.362	.252	1.659	33	.107	1.42760	.86077
	Equal variances not assumed			1.896	22.717	.071	1.42760	.75291
Beneath Chin	Equal variances assumed	.007	.932	1.100	27	.281	1.04444	.94946
	Equal variances not assumed			1.068	14.473	.303	1.04444	.97815

Supra orbital	Equal variances assumed	.229	.635	1.299	40	.201	.86861	.66872
	Equal variances not assumed			1.280	30.437	.210	.86861	.67838
Infra orbital	Equal variances assumed	4.475	.041	-.196	40	.845	-.11087	.56513
	Equal variances not assumed			-.229	38.165	.820	-.11087	.48417
Ectoconchion	Equal variances assumed	.465	.499	-1.078	40	.288	-.41264	.38287
	Equal variances not assumed			-1.128	36.426	.267	-.41264	.36578
Supra-Canine	Equal variances assumed	2.503	.123	-2.300	33	.028	-1.89860	.82542
	Equal variances not assumed			-2.868	28.128	.008	-1.89860	.66207
Jugale	Equal variances assumed	.012	.913	-1.897	33	.067	-1.50340	.79241

	Equal variances not assumed			-1.940	17.441	.069	-1.50340	.77506
Zygomatic Arch	Equal variances assumed	4.396	.044	-.750	33	.458	-1.04420	1.39150
	Equal variances not assumed			-1.048	32.999	.302	-1.04420	.99626
Euryon	Equal variances assumed	3.430	.072	1.112	37	.273	.31871	.28667
	Equal variances not assumed			.987	19.255	.336	.31871	.32300

Table 4.12- Results of T test 30-39 age group

T test result for 40-49 age group

Independent Samples Test								
Landmarks		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Bregma	Equal variances assumed	5.304	.027	-.799	39	.429	-.36613	.45819

	Equal variances not assumed			-.716	21.133	.482	-.36613	.51123
Glabella	Equal variances assumed	9.230	.004	-.086	39	.932	-.03233	.37373
	Equal variances not assumed			-.102	33.627	.919	-.03233	.31620
Nasion	Equal variances assumed	1.608	.212	2.225	39	.032	.87888	.39495
	Equal variances not assumed			2.307	35.767	.027	.87888	.38099
End of nasal bone	Equal variances assumed	2.284	.140	.627	35	.534	.12836	.20461
	Equal variances not assumed			.665	34.089	.510	.12836	.19295
Mid-philtrum	Equal variances assumed	1.016	.320	3.475	39	.001	2.79338	.80383
	Equal variances not assumed			3.933	38.751	.000	2.79338	.71029

Upper lip margin	Equal variances assumed	1.938	.172	3.654	36	.001	1.91572	.52432
	Equal variances not assumed			4.029	31.658	.000	1.91572	.47542
Lower lip margin	Equal variances assumed	2.755	.106	3.274	35	.002	1.74638	.53347
	Equal variances not assumed			3.870	34.986	.000	1.74638	.45128
Chin-lip fold	Equal variances assumed	.858	.361	1.836	35	.075	1.04031	.56657
	Equal variances not assumed			2.122	26.858	.043	1.04031	.49021
Mental eminence	Equal variances assumed	1.362	.252	1.659	33	.107	1.42760	.86077
	Equal variances not assumed			1.896	22.717	.071	1.42760	.75291
Beneath Chin	Equal variances assumed	.007	.932	1.100	27	.281	1.04444	.94946

	Equal variances not assumed			1.068	14.473	.303	1.04444	.97815
Supra orbital	Equal variances assumed	.229	.635	1.299	40	.201	.86861	.66872
	Equal variances not assumed			1.280	30.437	.210	.86861	.67838
Infra orbital	Equal variances assumed	4.475	.041	-.196	40	.845	-.11087	.56513
	Equal variances not assumed			-.229	38.165	.820	-.11087	.48417
Ectoconchion	Equal variances assumed	.465	.499	-1.078	40	.288	-.41264	.38287
	Equal variances not assumed			-1.128	36.426	.267	-.41264	.36578
Supra-Canine	Equal variances assumed	2.503	.123	-2.300	33	.028	-1.89860	.82542
	Equal variances not assumed			-2.868	28.128	.008	-1.89860	.66207

Jugale	Equal variances assumed	.012	.913	-1.897	33	.067	-1.50340	.79241
	Equal variances not assumed			-1.940	17.441	.069	-1.50340	.77506
Zygomatic Arch	Equal variances assumed	4.396	.044	-.750	33	.458	-1.04420	1.39150
	Equal variances not assumed			-1.048	32.999	.302	-1.04420	.99626
Euryon	Equal variances assumed	3.430	.072	1.112	37	.273	.31871	.28667
	Equal variances not assumed			.987	19.255	.336	.31871	.32300

Table 4.13- Results of T test 40-49 age group

T test result for 50-59 age group

Independent Samples Test							
Landmark	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference

Bregma	Equal variances assumed	.007	.933	-1.228	59	.224	-.42627	.34701
	Equal variances not assumed			-1.267	51.090	.211	-.42627	.33647
Glabella	Equal variances assumed	.208	.650	1.568	61	.122	.46300	.29526
	Equal variances not assumed			1.538	48.028	.131	.46300	.30114
Nasion	Equal variances assumed	1.147	.288	1.907	61	.061	.90457	.47439
	Equal variances not assumed			1.911	51.933	.061	.90457	.47323
End of nasal bone	Equal variances assumed	3.004	.088	2.303	59	.025	.45595	.19798
	Equal variances not assumed			2.736	54.649	.008	.45595	.16664

Mid - philtrum	Equal variances assumed	1.293	.260	6.049	60	.000	2.16700	.35824
	Equal variances not assumed			6.396	57.201	.000	2.16700	.33879
Upper lip margin	Equal variances assumed	.645	.425	4.472	60	.000	1.79570	.40156
	Equal variances not assumed			4.822	59.064	.000	1.79570	.37238
Lower lip margin	Equal variances assumed	.975	.327	3.823	59	.000	1.44767	.37872
	Equal variances not assumed			4.094	56.006	.000	1.44767	.35359
Chinlip	Equal variances assumed	.108	.743	.361	57	.719	.15143	.41931
	Equal variances not assumed			.342	35.427	.734	.15143	.44232

Mental eminence	Equal variances assumed	4.689	.035	2.285	55	.026	1.57421	.68905
	Equal variances not assumed			1.918	24.024	.067	1.57421	.82087
Beneath chin	Equal variances assumed	.420	.520	4.344	52	.000	1.72365	.39679
	Equal variances not assumed			4.059	24.552	.000	1.72365	.42467
Supra orbital	Equal variances assumed	.003	.959	-.516	61	.608	-.22861	.44330
	Equal variances not assumed			-.511	49.877	.612	-.22861	.44743
Infra orbital	Equal variances assumed	4.181	.045	-1.251	61	.216	-.50534	.40385
	Equal variances not assumed			-1.162	38.987	.252	-.50534	.43495
Ectoconchion	Equal variances assumed	3.630	.061	-1.405	61	.165	-.26259	.18686

	Equal variances not assumed			-1.309	39.441	.198	-.26259	.20065
Supra canine	Equal variances assumed	.753	.404	.016	11	.988	.01444	.90242
	Equal variances not assumed			.013	3.783	.991	.01444	1.15080
Jugale	Equal variances assumed	2.289	.135	-3.217	61	.002	-1.63268	.50753
	Equal variances not assumed			-3.060	42.812	.004	-1.63268	.53357
Zygomatic Arch	Equal variances assumed	4.873	.031	-.405	61	.687	-.28265	.69757
	Equal variances not assumed			-.371	36.878	.713	-.28265	.76221
Supra Glenoid	Equal variances assumed	.320	.573	.803	61	.425	.47023	.58590

	Equal variances not assumed			.773	44.824	.444	.47023	.60865
Euryon	Equal variances assumed	3.948	.052	-.136	60	.892	-.03498	.25751
	Equal variances not assumed			-.149	59.901	.882	-.03498	.23478
SupraM2	Equal variances assumed	.054	.822	-1.295	8	.231	-2.6750	2.0649
	Equal variances not assumed			-1.267	6.086	.252	-2.6750	2.1114

Table 4.14- Results of T test 50-59 age group

The results of the Levene's test indicates whether the variances of the 2 gender groups are equal or not ($P<0.05$). When the variances were equal the significance column of the T test corresponding to the **Equal variance assumed** row was considered. When the variances were not equal the significance column of the T test corresponding to the **Equal variance not assumed** row was considered. [53]

4.6. Comparison of Sri Lankan Facial Tissue Thickness Values with Foreign populations

4.6.1. Z Test Analysis

Below results show the results of the Z test analysis which was performed to measure the level of deviation of foreign studies with the Sri Lankan study.

The result is significant at $p < 0.05$. The FSTT values which show less significant differences with the FSTT of the Sri Lankan study are marked in red.

The cells which are indicated as N/A are for the landmarks which are not included in the particular foreign study.

20 - 29 Male Population

	NW		Taiwanese		Turkish	
Landmark	**Z statistic**	**P value**	**Z statistic**	**P value**	**Z statistic**	**P value**
Bregma	N/A	N/A	N/A	N/A	N/A	N/A
Glabella	3.44941896	0.000562.	1.012753587	0.311203	-1.963708829	0.049646.
Nasion	2.611808757	0.009007	0.828442268	0.407444	-0.5096614326	0.610752
End of nasal bone	9.757154026	< 0.00001.	0.238410048	0.811571	2.498998661	0.012458
Mid philtrum	5.076726326	< 0.00001.	1.840155805	0.065754	1.406924522	0.159457
Upper lip margin	6.376754676	< 0.00001.	1.404096266	0.160319	-1.985598326	0.047144
Lower lip margin	0.2053835293	0.837338	2.967116295	0.003006	-5.157472033	< 0.00001
Chin-lip fold	8.155277397	< 0.00001	-0.5307791586	0.596112	3.886072442	0.000102.
Mental eminence	3.071637869	0.002129	0.9811686034	0.326543	-0.4065699405	0.684743
Beneath Chin	0.5270682642	0.598194	0.4146338906	0.678435	0.2881136817	0.77327
Supra orbital	1.888192898	0.059013	1.534559816	0.124907	2.542646195	0.011003.
Infra orbital	5.724173626	< 0.00001	-1.428348204	0.153292.	0.7409484668	0.458754
Ectoconchion	-1.170564585	0.242001	N/A	N/A	0.3706080679	0.710935
Jugale	N/A	N/A	-0.2054975922	0.837572	-1.56177066	0.118524
Zygomatic arch	N/A	N/A	-1.534884937	0.12503	-0.3993426373	0.689893
Supra glenoid	N/A	N/A	0.05064595453	0.959644	-2.748171538	0.005996

Table 4.15- Results of Z test 20-29 age group (Male)

20 - 29 Female population

	North West Indian		Taiwanese		Turkish	
Landmark	**Z statistic**	**P value**	**Z statistic**	**P value**	**Z statistic**	**P value**
Bregma	11.32775511	< 0.00001	N/A	N/A	N/A	N/A
Glabella	2.26450827	0.023543	1.758727439	0.078628	-0.6481544241	0.843828
Nasion	1.511730115	0.13061	2.943910468	0.001769	-1.710476249	0.087266
End of nasal bone	3.707465636	0.000209.	3.36146216	0.000531	2.551872614	0.010717
Mid philtrum	4.921176791	< 0.00001	0.7732329259	0.439404	2.201170479	0.027729
Upper lip margin	3.201363296	0.001368.	2.290335458	0.055352	0.5471418813	0.58431
Lower lip margin	0.1227812527	0.902345	3.841250081	0.000122	-0.5341172919	0.59334
Chin-lip fold	4.753892944	< 0.00001	-0.1490141431	0.881554	3.326748943	0.000879
Mental eminence	3.676214612	0.000237.	0.1065425789	0.915186	1.059222844	0.289509
Beneath Chin	-3.279509186	0.001042	1.013497678	0.310869	0.487783044	0.625762
Supra orbital	4.14598543	3.40E-05	5.88174016	< 0.00001	4.943958054	< 0.00001
Infra orbital	5.704213026	< 0.00001	0.7843288108	0.432864	3.195289301	0.001397
Ectoconchion	0.8992493132	0.368546	N/A	N/A	3.566863076	0.000361
Jugale	N/A	N/A	-0.1979898987	0.843828.	-5.99008848	< 0.00001
Zygomatic arch	N/A	N/A	-1.500528802	0.133614.	0.3171591407	0.751168
Supra glenoid	N/A	N/A	1.492451607	0.135594	1.423558273	0.154591

Table 4.16- Results of Z test 20-29 age group (Female)

30 - 39 Male population

Landmark	North West Indian		Taiwanese		Turkish	
	Z statistic	p value	Z statistic	p value	Z statistic	p value
Bregma	5.795296104	< 0.00001.	N/A	N/A	N/A	N/A
Glabella	3.149167588	0.001638.	-0.5418532422	0.588508	-2.601273179	0.009295.
Nasion	3.887158955	0.000101.	0.01221340117	0.990266	-1.442129912	0.149302.
End of nasal bone	9.450084915	< 0.00001.	2.317121349	0.234361	1.84194849	0.06549.
Mid-philtrum	4.451397632	< 0.00001.	2.287064764	0.022196	2.961869144	0.003058.
Upper lip margin	3.751959075	0.000175.	-0.0054768014	0.996011	-0.7478238747	0.455064
Lower lip margin	1.199364519	0.230411.	6.928389456	< 0.00001.	-3.144945147	0.001667.
Chin-lip fold	10.78152021	< 0.00001.	-0.8771853796	0.380487.	6.11716261	< 0.00001.
Mental eminence	7.334316652	< 0.00001.	2.144544978	0.031993.	1.447507262	0.147757.
Beneath Chin	-0.4220086032	0.673025.	-0.0908014513	0.928287.	-0.7679671822	0.443082.
Supra orbital	2.779573985	0.005444.	1.128475591	0.259151.	1.551003826	0.120902
Infra orbital	7.851400469	< 0.00001.	-0.5211758975	0.602367.	0.9189213556	0.358148.
Ectoconchion	0.3366423895	0.736418.	N/A	N/A	2.022513156	0.043125
Supra-Canine					15.21876272	< 0.00001
Jugale			-0.2033021683	0.839135.	-0.6160457036	0.537895
Zygomatic arch			-0.7090723735	0.478324.	0.8979707685	0.369239.
Supra glenoid			-0.1959193843	0.845393	-3.90018075	< 0.00001

Table 4.17- Results of Z test 30-39 age group (Male)

30 - 39 Female Population

Landmark	North West Indian		Taiwanese		Turkish	
	z statistic	p value	z statistic	p value	z statistic	p value
Bregma	11.24305094	< 0.00001				
Glabella	0.7628617537	0.445583.	1.543627866	0.122685.	-1.664979216	0.096112.
Nasion	0.7552843913	0.450129	0.3385408548	0.734986.	-3.42901896	0.000606.

End of nasal bone	5.690934915	< 0.00001	0.1221347403	0.90282.	3.344932848	0.000823
Mid-philtrum	1.157374782	0.24715.	0.6055094962	0.544847.	1.644385068	0.100114
Upper lip margin	0.7494631656	0.453616	0.673367006	0.500756	0.4124617757	0.680046
Lower lip margin	-1.19453862	0.232478	0.8888755652	0.374111.	-2.899839608	0.003744
Chin-lip fold	8.323117066	< 0.00001	-0.7101104489	0.477704	5.929058436	< 0.00001.
Mental eminence	5.917654332	< 0.00001	1.592184267	0.111362.	-0.3581855798	0.720343.
Beneath Chin			1.0481827	0.294593.	0.9142821631	0.360612
Supra orbital	2.390607519	0.016821	0.9005116488	0.367854.	3.2471297	0.001166.
Infra orbital	5.157754359	< 0.00001	-1.053511637	0.292341	0.9620473075	0.33605.
Ectoconchion	1.756493263	0.07902.			3.726688167	0.000194.
Jugale			1.198437968	0.230761	1.144557535	0.252416.
Zygomatic arch			-0.4700402454	0.638355.	3.453415412	0.000554.
Supra glenoid			0.1837621532	0.854249.	0.3218896802	0.747604.
Supra M2	2.949471992	0.003184	2.949471992			0.25894.

Table 4.18- Results of Z test 30-39 age group (Female)

40 - 49 Male Population

	North West Indian		Taiwanese		Turkish	
Landmark	**Z statistic**	**p value**	**Z statistic**	**p value**	**Z statistic**	**p value**
Bregma						
Glabella	3.704486576	0.000212	0.8437344108	0.398837	-1.405654898	0.160021
Nasion	5.359961824	<0.00001	-0.1903364439	0.849309	-2.276050681	0.022846
End of nasal bone	8.741583611	<0.00001	2.424464685	0.015351	-2.078770283	0.038452
Mid-philtrum	4.741908476	<0.00001	0.4307241242	0.666687	0.4343104629	0.664071
Upper lip margin	2.384402476	0.017107	-0.2596937943	0.795635	-3.619034895	0.000296
Lower lip margin	2.188077484	0.02867	4.304699863	<0.00001	-1.98958844	0.046701
Chin-lip fold	8.460303595	<0.00001	-0.8886613575	0.374541	4.956141532	<0.00001
Mental eminence	8.061350085	<0.00001	1.629688918	0.103186	0.5026235048	0.615246
Beneath Chin	-1.425694074	0.142921	-1.009402702	0.312975	-2.428024651	0.015182

Supra orbital	7.552015074	<0.00001	3.641148903	0.000271	5.123662389	<0.00001
Infra orbital	6.316076542	<0.00001	-0.04357106012	0.965702	2.536585351	0.011197
Ectoconchion	2.745999411	0.006033			4.310387072	<0.00001
Supra-Canine					5.279730633	<0.00001
Jugale			0.4975096071	0.618837	-0.6276803983	0.530659
Zygomatic arch			0.3724006577	0.709595	2.069650767	0.03849
Supra glenoid			0.3239116266	0.746014	-5.057112187	<0.00001
Supra M2	9.146846757	<0.00001	23.1203118		-3.21287353	0.001318

Table 4.19- Results of Z test 40-49 age group (Male)

40 - 49 Female Population

	North West Indian		Taiwanese		Turkish	
Landmark	**z statistic**	**P value**	**z statistic**	**P value**	**z statistic**	**P value**
Bregma	10.86881001	< 0.00001				
Glabella	0.6424102643	0.520613	1.039102163	0.298758.	-3.773692492	0.000161
Nasion	-0.4803696854	0.631227	0.4647128439	0.642146.	-4.530970593	0.00001
End of nasal bone	6.078796876	<0.00001	-0.1742288939	0.861865.	3.108341608	0.001882
Mid-philtrum	3.196846074	0.00139	1.437205754	0.150661.	1.285406907	0.198653
Upper lip margin	-2.661581177	0.007791	0.5305755976	0.595765.	-3.415657988	0.000638
Lower lip margin	-2.604800978	0.009214	-0.8459107329	0.398111.	-3.961478183	<0.00001
Chin-lip fold	7.048615244	<0.00001	-1.546029672	0.122105.	4.538353706	<0.00001
Mental eminence	2.830643143	0.004646	0.1353642903	0.892375.	-3.113263392	0.001852
Beneath Chin	-2.367043408	0.017933	-1.478246659	0.139408.	-0.524736607	0.600279.
Supra orbital	6.860126136	<0.00001	1.96500225	0.049414.	4.38922923	<0.00001
Infra Orbital	8.533561716	<0.00001	-0.1875622964	0.851661.	2.243898306	0.024845.
Ectoconchion	0.8232811987	0.410394			2.719416136	0.00654.
Supra-Canine					3.86415495	0.000111.
Jugale			-0.2576732667	0.797179.	-4.027805269	<0.00001
Zygomatic arch			-1.101954684	0.270897.	0.08124229263	0.935283.

Supra glenoid			0.1534173892	0.878083.	-4.391230801	<0.00001
Euryon						
Supra M2			1.92999258	0.053619.	-2.966758865	0.003017.

Table 4.20- Results of Z test 40-49 age group (Female)

50 - 59 Male Population

	North West Indian		Taiwanese		Turkish	
Landmark	**Z statistic**	**p value**	**Z statistic**	**p value**	**Z statistic**	**p value**
Bregma	13.10843053	< 0.00001.				
Glabella	5.803768442	< 0.00001.	1.108298023	0.267775	-3.680718389	0.000233.
Nasion	3.091947942	0.001989.	0.06420274629	0.342722	-3.714373551	0.000204.
End of the nasal bone	15.65368378	< 0.00001.	2.734380144	0.006251	-5.142157562	< 0.00001.
Mid-philtrum	5.243240679	< 0.00001.	0.8827384015	0.377398	0.5468206695	0.584516.
Upper lip margin	3.000459185	0.002696.	0.01601377924	0.987234	-2.941324874	0.003272.
Lower lip margin	0.3508114721	0.725738.	2.110632154	0.987234	-4.239799914	2.2E-05.
Chin-lip fold	10.60621765	< 0.00001.	-0.7343663112	0.462949	4.635761028	< 0.00001.
Mental eminence	6.997212093	< 0.00001.	1.076641802	1.076641802	-1.67579053	0.093934.
Beneath Chin	0.07400880022	0.94101.	0.1755515377	0.860687	-2.288098402	0.022138.
Supra-orbital	3.849252503	0.000119	1.316413087	0.18804	2.609383734	0.009073.
Infra orbital	8.513861954	< 0.00001	-0.4600792698	0.645516	0.1782010894	0.858566.
Ectoconchion	2.922327694	0.003475			3.637192854	0.000276.
Supra-canine					2.798230783	0.005139.
Jugale			0.1443424069	0.885264	-0.9316773084	0.351854.
Zygomatic arch			-0.1190766138	0.905275	2.41657683	0.015671.
Supra glenoid			0.5138369117	0.607392	-4.950446316	<0.00001
Supra M2	0.9284963319	0.3532	4.081386913	< 0.00001.	-4.751054441	< 0.00001.

Table 4.21- Results of Z test 50-59 age group (Male)

50 - 59 Female Population

	North West Indian		Taiwanese		Turkish	
Landmark	**Z statistic**	**p value**	**z statistic**	**p value**	**z statistic**	**p value**
Bregma	10.29353084	< 0.00001.				
Glabella	5.162327118	< 0.00001.	2.91810625	0.003522.	-1.980296924	0.047704.
Nasion	1.438680878	0.150264.	0.8445778995	0.39839.	-3.458942047	0.000544.
End of the nasal bone	7.676246418	< 0.00001.	6.098599518	< 0.00001.	-0.9970086007	0.318765
Mid-philtrum	3.52641037	0.000421.	1.088465117	0.276419.	1.104010583	0.269593
Upper lip margin	-2.156961619	0.031084.	0.3605481182	0.718473.	-7.431556052	< 0.00001
Lower lip margin	-1.302694513	0.192916	2.918027742	0.003523.	-6.001466633	< 0.00001
Chin-lip fold	7.804058428	< 0.00001.	-1.682308038	0.092569.	4.105523345	4.00E-05
Mental eminence	5.325846125	< 0.00001.	2.598436892	0.009366.	1.171888908	0.241277.
Beneath Chin	0.0686025831 6	0.945308.	-1.875444495	0.060793.	-1.162911836	0.245235
Supra-orbital	8.913335256	< 0.00001.	4.363073148	<0.00001	7.851318774	< 0.00001
Infra orbital	13.87369492	< 0.00001.	1.592160495	0.111362.	6.64763889	< 0.00001
Ectoconchion	5.319156474	< 0.00001.			6.55867723	< 0.00001
Supra-canine					7.29330194	< 0.00001
Jugale			2.075396408	0.037959.	-2.155647367	0.031162
Zygomatic arch			0.1791685025	0.857859.	1.361804818	0.031162
Supra glenoid			1.717872023	0.085833.	-1.192928795	0.233261.

Table 4.22- Results of Z test 50-59 age group (Female)

From the Z statistic computed and the corresponding p value it shows that majority of the FSTT values of the landmarks from the Taiwanese study have less significance differences with the FSTT values of the Sri Lankan study with compared to other two foreign studies.

4.7 Results of the Principal Component Analysis (PCA) and Factor Analysis (FA)

4.7.1 Results of PCA and FA for 40-49 Age Range

Summarized results of the **princomp()** function, resulted giving Standard deviation, Proportion of Variance and Cumulative Proportion. Using the Proportion of Variance row it can be concluded that the first component explains 52% of variance, second component explains a 12% of variance, third component explains 9% of variance, fourth component explains 5% of variance and thereafter the variation decreases with a minimal difference between proportions. Accordingly it seemed better to retain four components.

```
Importance of components:
                          Comp.1    Comp.2     Comp.3     Comp.4     Comp.5
Standard deviation     4.9662418 2.4277343 2.15591389 1.58764910 1.44373520
Proportion of Variance 0.5222718 0.1248082 0.09842461 0.05337648 0.04413834
Cumulative Proportion  0.5222718 0.6470801 0.74550469 0.79888117 0.84301951
                           Comp.6    Comp.7     Comp.8     Comp.9    Comp.10
Standard deviation     1.32731272 1.1816326 1.10224365 0.86504860 0.81520370
Proportion of Variance 0.03730675 0.0295669 0.02572741 0.01584608 0.01407256
Cumulative Proportion  0.88032626 0.9098932 0.93562058 0.95146666 0.96553922
                          Comp.11     Comp.12     Comp.13     Comp.14
Standard deviation     0.71097945 0.680592121 0.536595890 0.450466034
Proportion of Variance 0.01070422 0.009808774 0.006097272 0.004296997
Cumulative Proportion  0.97624344 0.986052218 0.992149490 0.996446487
                          Comp.15     Comp.16      Comp.17
Standard deviation     0.28057812 0.220144851 0.2015486547
Proportion of Variance 0.00166705 0.001026261 0.0008602025
Cumulative Proportion  0.99811354 0.999139797 1.0000000000
```

Figure 4.5 - Summary resulted by PCA

Following scree plot gained (shown in the figure 4.6) also show that after 4 factors the slope of the curve is clearly leveling off creating an “elbow”. The elbow which is meant by here is the point where the line of the graph starts to smooth up (where curve starts to flatten). There by using the **scree plot** gained also we could able to conclude that it is ideal to retain four components/ factors.

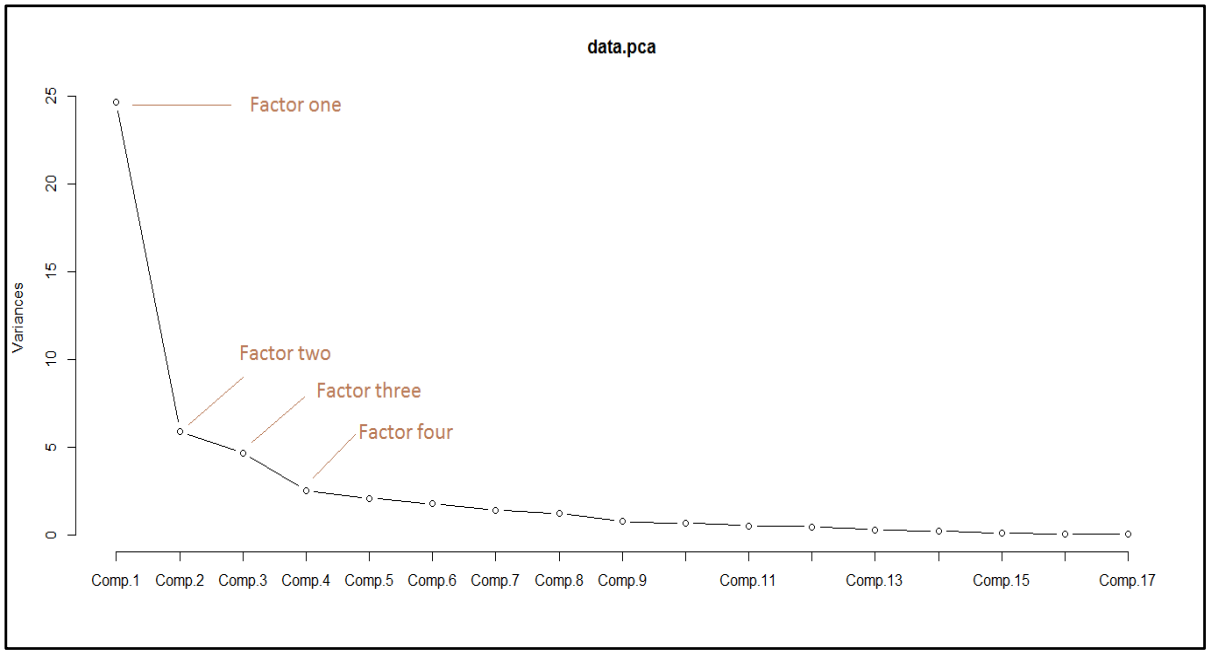


Figure 4.6 - Scree plot for the 40-49 age range

The results of the Factor Analysis computed for the male 40-49 age category and 50-59 category separately are as below. After performing factor analysis for the 40-49 age range using 'factanal' function for the above four components/ factors, the following landmarks were grouped together.

Factor 1- Infra orbital, Jugale, Zygomatic arch, Supra glenoid, Ectoconchion

Factor 2- Mid philtrum, Upper lip margin, Supra orbital, Glabella, Beneath chin

Factor 3 - Nasion, End of nasal bone, Lower lip margin, Chin lip fold, Mental eminence

Factor 4 - Bregma, Euryon

4.7.2 Results of PCA for 50-59 Age Range

Below are the summarized results gained through the PCA applied to the 50-59 age range data set. Using the Proportion of Variance row it could be concluded that the first component explains 22% of variance, second component explains a 16% of variance, third component explains 12% of variance, fourth component explains 8% of variance and thereafter the variation decreases further down to a lower value giving a minimal difference between proportions of variance. So according to this, similarly as in the 40-49 age range, in 50-59 age range also, it seems like it is ideal to retain 4 components.

```
Importance of components:
                          Comp.1     Comp.2     Comp.3
Standard deviation     2.8280787 2.4143283 2.0892379
Proportion of Variance 0.2281969 0.1663104 0.1245382
Cumulative Proportion  0.2281969 0.3945072 0.5190454
                           Comp.4     Comp.5     Comp.6
Standard deviation     1.71885414 1.66638781 1.51612902
Proportion of Variance 0.08429556 0.07922803 0.06558416
Cumulative Proportion  0.60334095 0.68256898 0.74815314
                           Comp.7     Comp.8     Comp.9
Standard deviation     1.40553700 1.26660372 1.16082594
Proportion of Variance 0.05636522 0.04577287 0.03844686
Cumulative Proportion  0.80451837 0.85029124 0.88873810
                          Comp.10    Comp.11    Comp.12
Standard deviation     0.96900132 0.94871381 0.7992889
Proportion of Variance 0.02679017 0.02568012 0.0182278
Cumulative Proportion  0.91552827 0.94120839 0.9594362
                          Comp.13    Comp.14     Comp.15
Standard deviation     0.73570564 0.60369978 0.518405191
Proportion of Variance 0.01544311 0.01039845 0.007667704
Cumulative Proportion  0.97487930 0.98527775 0.992945459
                          Comp.16     Comp.17
Standard deviation     0.372461126 0.329432856
Proportion of Variance 0.003958116 0.003096424
Cumulative Proportion  0.996903576 1.000000000
```

Figure 4.7 - Summarized results of PCA

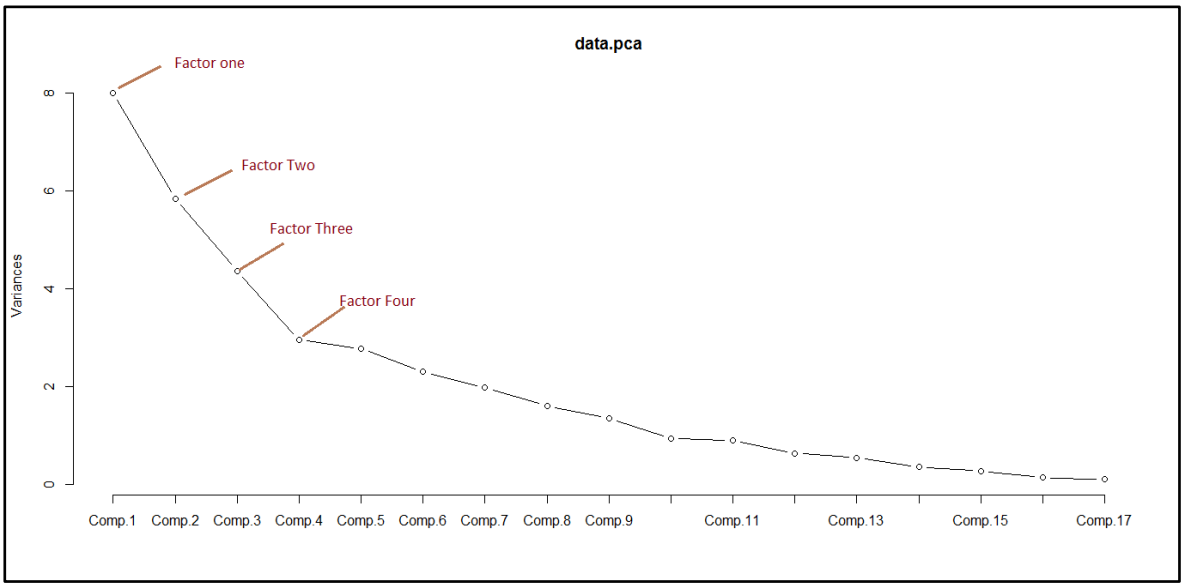


Figure 4.8 - Scree plot for the 40-49 age range

After performing factor analysis for the 50-59 age range using ‘factanal’ function for the above four components/ factors, the following landmarks were grouped together.

Factor 1 – Supra orbital, Glabella, Nasion, End of nasion, Upper lip, Mid philtrum

Factor 2 - Jugale, Zygomatic Arch, Supra glenoid, Ectoconchion, Infra orbital

Factor 3 - Lower lip, Chin lip, Mental eminence, Bregma

Factor 4 - Euryon, Beneath chin

4.8 Results of the Regression Tree Analysis

4.8.1 Results of Regression Tree Analysis for 40-49 Age Range

When applied 'rpart' function for the factor 2 landmarks (as mentioned in the section 4.7.1) in order to find the average values for landmark Zygomatic arch the following result was given as the output.

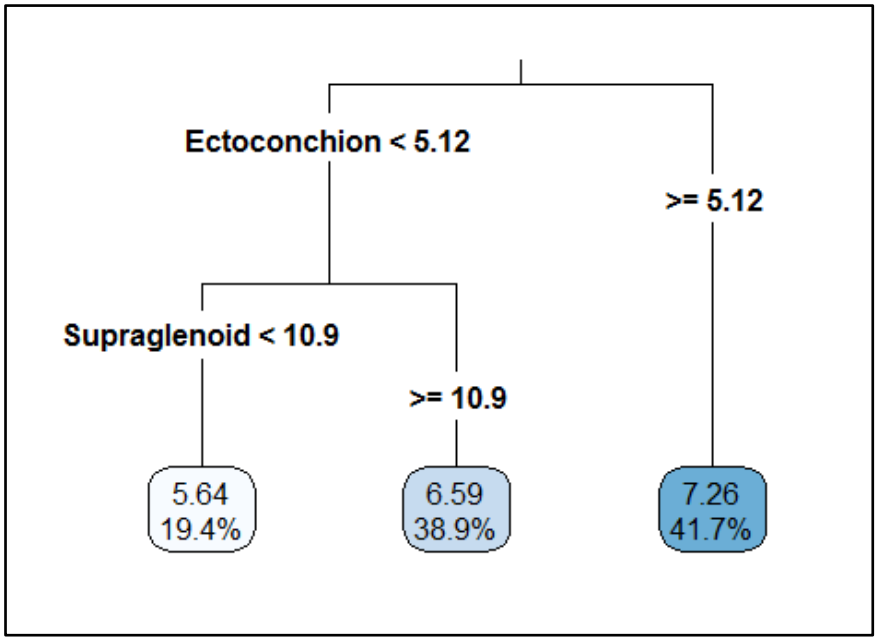


Figure 4.9 - Regression tree analysis for finding Zygomatic arch for 40-49 male population

According to the above result for the given data set, it shows for a male in between 40-49 age range, if Ectoconchion is greater than or equal 5.12 mm, the predicted average value for the Zygomatic arch is 7.26 mm, if Ectoconchion is lesser than 5.12 mm and Supra glenoid is lesser than 10.9 mm predicted average value for Zygomatic arch is 5.64 mm and if Ectoconchion is lesser than 5.12 mm and Supra glenoid is greater than or equal 10.9 mm the Zygomatic arch can be 6.59 mm.

4.8.2 Results of Regression Tree Analysis for 50-59 Age Range

When applied 'rpart' function for the factor 2 landmarks (as mentioned in the section 4.7.2) in order to find the average values for landmark Zygomatic arch the following result was given as the output.

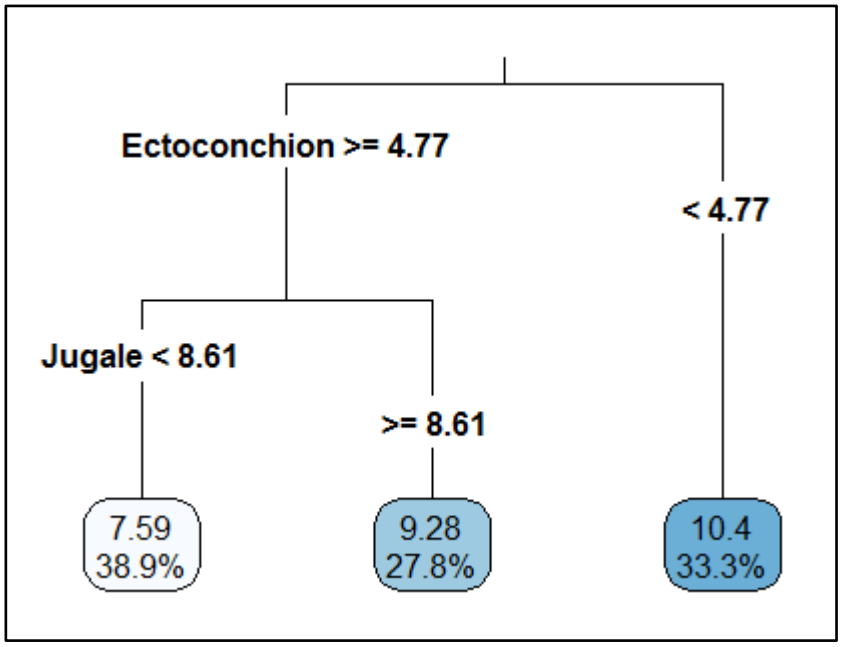


Figure 4.10 - Regression tree analysis for finding Zygomatic arch for 50-59 male population

According to the above result for the given data set, it shows for a male in between 50-59 age range, if Ectoconchion is lesser than 4.77 mm, the predicted average value for the Zygomatic arch is 10.4 mm, if Ectoconchion is greater than or equal 4.77mm nd Jugale is lesser than 8.61 mm predicted average value for Zygomatic arch is 7.59 mm and if Ectoconchion is greater than or equal 4.77mm and Jugale is greater than or equal 8.61 the Zygomatic arch can be 9.28 mm.

4.9. Results of the Random Forest Regression Method

During the important measure calculation the following output was generated.

Landmark	%IncMSE	IncNodePurity
Zygomatic Arch	20.29701	33.8231179
Jugale	14.65308	28.7828375
Infra Orbital	11.57330	25.7978221

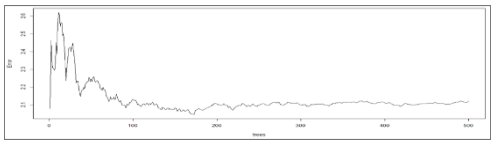
Ectoconchion	15.07005	27.7799175
Age	0.02872	0.6946763

Table 4.23 - Importance of the variables of the selected Principal Component

It was observed that for tissue thickness of Supra Glenoid only the tissue thickness of other four landmarks - Infra Orbital, Ectoconchion, Jugale and Zygomatic Arch affects a lot. The effect of age for its tissue thickness is not significant when considered with those.

Once the importance of the variable was checked with R statistical software, the optimum number of trees needed for the random forest is calculated.

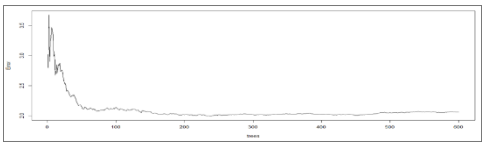
For 500 trees



Mean of squared residuals - 2.2399

Figure 4.11- Plot for 500 trees

For 600 trees



Mean of squared residuals - 2.0056

Figure 4.12 - Plot for 600 trees

The generated results of the analysis for finding the optimal number of trees for the random forest analysis (Figure 4.11) shows that if 500 trees are used for the forest, the mean of squared residuals is 2.2399. If 600 trees are used this value is 2.0056. The lowest mean of squared residuals was given for 600 trees. So further analysis was done with 600 trees.

After applying regression tree and random forest (using same training and testing sets) to predict the value of Supra glenoid, MAE, RMSE and MAPE was calculated to evaluate the most appropriate learning method out of the two methods for the missing tissue thickness value imputation.

Regression tree		Random forest	
RMSE	1.514892	RMSE	1.452337
MAE	1.258369	MAE	1.175
MAPE	10.55894	MAPE	9.504295

Table 4.24-. RMSE, MAE and MAPE comparison for the results of the Regression tree and Random forest

4.10. Results of the Facial Reconstruction

From the adapted two learning methods it was observed that Random Forest regression was the most applicable method which showed minimum error value. Hence, the facial reconstruction was performed based on the imputed values using Random Forest Regression method.

Below figures are the different views of the resultant face created with the interpolated values mentioned in 4.8.1 using ZBrush™ software. The lateral view (Figure 4.13) shows the 3 landmarks reconstructed, A- Jugale, B- Zygomatic Arch and C-Supra Glenoid respectively.

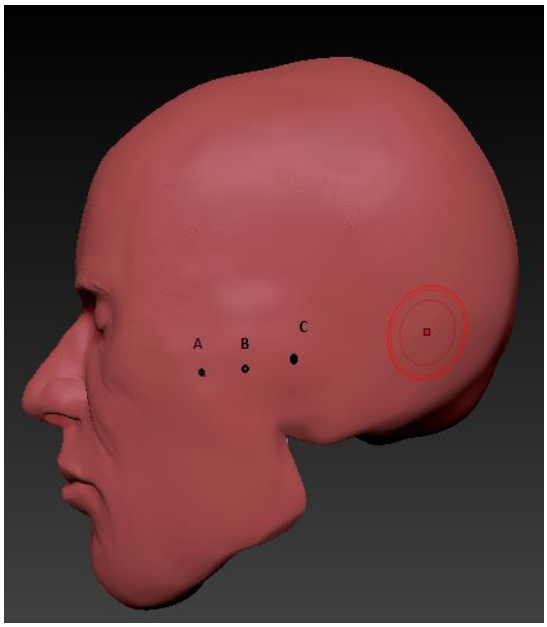


Figure 4.13. Lateral view of the reconstructed face

Figure 4.14. Frontal view 1 of the reconstructed face

Figure 4.15. Frontal view 2 of the reconstructed face

Since the reconstructed case was a highly confidential case, authors had no rights to view the photographic images of the case. Therefore, we have already sent the reconstructed face for validation purposes to relevant parties.

Chapter 5 - Discussion

5.1 Introduction

The purpose of this study was threefold. Firstly, a facial soft tissue thickness (FSTT) database for the Sri Lankan adult population within the age category 20-59 years was developed which could be used in forensic facial reconstruction (FFR), Facial sculpturing purposes and plastic surgeries. This was carried out by measuring the soft tissues on MRI scans of 243 patients of National Hospital Colombo.

Predetermined landmarks were identified and measured on Sagittal, Axial and Coronal plans of MRI. The average of the measurements at each landmark was calculated as the average FSTT at that particular landmark

The second purpose was to assess the possibility of creating a unified FSTT model for the Sri Lankan population and estimate the possibility of finding missing values (values of the landmarks which are not covered by MRI images) from statistical interpolation methods. Here average FSTT values of three foreign studies were compared with the Sri Lankan study to evaluate which study would show close relationship with the Sri Lankan FSTT values and would do better in statistical interpolation.

The third purpose of this study with the completion of first and second objectives was to test the accuracy and recognisability of faces after being reconstructed with the newly established data. A new case was constructed based on a known skull (age and sex know) which an ante-mortem photograph (which the victim could be positively identified) of the victim was available. Based on the percentage similarity of the reconstructed skull to the actual photograph the accuracy is to be defined upon the approval of authorized parties.

This chapter will further describe results of the outcomes of the statistical analyses and learning methods, drawbacks and problems experienced during the study

5.2 Discussion of Results

5.2.1 Comparison of FSTT within Gender Groups

Based on the results of the graphical representations and the T test analysis it was observed that the FSTT at Mid philtrum has a significant difference between the two genders across all the age groups .The FSTT at Nasion landmark was significantly different between males and females within 20-49 age range. FSTT at Lower Lip and Upper Lip landmarks showed considerable difference between the two gender groups within the age range 30-59. The FSTT at Jugale and Beneath Chin showed significant difference between 50-59 age group.

Other landmarks such as the Bregma, Glabella, End of Nasal Bone, generally showed less variation between the 2 gender groups.

In general men have higher FSTT than women. The area along the midline of men always shows higher FSTT than female. The area around the cheeks (represented by Jugale, Zygomatic Arch and Supra Glenoid) also show comparatively large tissue thickness in young men (within 20-39 age range) than in women.

Rhine and Campbell [9] also have discovered in their research work (which was done for Black Americans) that males normally have thicker soft tissues than females, but with the exception of the region beneath the eyes. The reason they have provided for their conclusion is presence of larger skulls and larger muscles attachments. A study by Wilkinson et al. [47] has showed that the majority of the facial points of males have thicker tissues than females, especially at the brow, mouth, and jaw areas.

Researchers have recognized that fundamental differences exist in facial tissue depth between the gender groups because of differences in skull morphology.

5.2.2 Trend Line Analysis of the Comparison of the FSTT within Age groups

By analysing the graphical visualizations it was observed that the thickness at some landmarks decrease or increase with age while some do not show a specific formal pattern variation with aging.

In males 40-49 age group has the highest number of FSTT peaks including the FSTT at Bregma, Glabella, Nasion, End of Nasal Bone, Lower Lip margin, Upper Lip Margin, Chin Lip fold, Supra orbital, Infra orbital, Ectoconchion, Jugale, Zygomatic Arch, and Euryon landmarks, while FSTTs at other landmarks are also considerably high. This finding persuades that males have the highest FSTT at the age range of 40-49.

In females the highest numbers of FSTT peaks are represented by 50-59 age category including the FSTT at Glabella, Supra orbital, Infra orbital, Ectoconchion, Jugale, Zygomatic Arch, Supra glenoid and Euryon while FSTT at Upper Lip margin landmark showed minimum FSTT at 50-59 age range.

In both females and males FSTTs at Bregma, Glabella, End of Nasal Bone and Nasion do not show a direct relationship with aging. In males, beneath chin also does not show much variance with aging. But in females FSTT at Beneath Chin shows a slight increase with the age.

In both males and females FSTTs at points like Mid philtrum and Upper Lip Margin gradually decrease with the age. In females the FSTTs at Supra Orbital, Jugale, Zygomatic arch and Supra Glenoid landmark increase with age. Males have the least FSTT mean for Supra Orbital, Jugale, Zygomatic arch and Supra glenoid landmarks at the age range 20-29, but it doesn't show a direct or inverse relationship between FSTT and age when other age ranges are considered.

The differences of the tissue thickness may be attributed to variation of the deposition of fat with aging. Also in a study by Manavpreet Kaur et al. [56] researchers have explained several causes for the variation of FSTT with aging. Among them they have showed that skin related deformations associated with the introduction of wrinkles and the reduction of muscle strength with aging affects the decrease of FSTT.

5.2.3. Comparison with Foreign Studies

With the comparison of raw data and average FSTT values and performance of the Z test analysis (by considering the p value corresponding to the Z statistic) it depicted that majority of FSTTs at landmarks of the Taiwanese population (Glabella, Nasion, Mid philtrum, Upper lip margin, Lower lip margin, Chin Lip fold, Mental eminence, Beneath Chin, Supra Orbital, Infra Orbital, Jugale, Zygomatic Arch and Supra Glenoid) had less significant difference with the Sri Lankan population compared to other two studies. With that, a finding was made as the, foreign population which showed closer relationship with the Sri Lankan study is the Taiwanese population.

An assumption was also made as the three foreign data samples are normally distributed because no literature indicated that the sample distributions are normal.

However, this ground finding cannot be directly employed in the statistical interpolation process because this finding was made only by assuming the normality of the samples are true and neither of the raw data was published in a standard publication. Also sample size of some of the age categories of foreign studies were not sufficient enough to perform statistical tests, even the minimum sample size of Sri Lankan age categories is 19 . Hence, both sample sizes were not enough to come in to a standard statistical conclusion.

Therefore, further research work is needed to modify and establish this claim with the persistence of more raw data samples from both populations and go for statistical interpolation. Despite, in this study missing values were interpolated using consecutive age ranges. Thus, this finding can be used as a base for future work.

5.2.4 Result of the Learning Methods Applied

In the path to assessing the possibility of devising a unified FSTT model statistical analysis and learning methods were performed. Principal component analysis (PCA) and factor analysis (FA) were applied in order to reduce the number of variables to be considered when devising the unified facial soft tissue thickness (FSTT) model by performing the dimensionality reduction.

As represented in the graphical representations the pattern of variation of trend lines (between foreign populations) are non-uniform. Hence a common difference was not found and it needed some higher mathematical background to study the pattern of variation. With the limited time constraints the study of this mathematical approach was not possible.

And without raw data it was not possible to claim that the distribution of Taiwanese sample is normal. The normality of the South African Black females sample which the raw data was present was also checked but the sample distribution was not normal. Therefore, missing value imputation from foreign values was not performed.

Due to above reason and since landmarks - Supra canine, Infra canine, Mastoidale, Supra M2, Sub M2 - did not have sufficient samples (minimum of 30) to perform PCA and FA, it was unable to consider all 23 landmarks used during the study for the dimensionality reduction process. Hence with the available data 17 landmarks were chosen for the process of dimensionality reduction.

Through PCA and factor analysis performed for age range (40-49 and 50-59) it was observed that landmarks which located closer have some common relationship since they were clustered in a common factor. For example in 40-49 age range the five landmarks namely, Jugale, Zygomatic arch, Supra glenoid, Ectoconchion and Infra orbital which are located closer, group under factor 01. Similarly the same five landmarks group under factor 02 in 50-59 age range.

With the regression tree analysis (the learning method) performed for the landmarks grouped within principal components can find an average of FSTT values for a specific landmark which could be chosen by the reconstructor. The output can be gained through a combination of relevant landmarks within that factor. The approach of regression tree can be used during the plastic surgeries, where a part of the face is to be reconstructed. For example if it is needed to reconstruct the area below the nose (area which includes Upper lip margin & Mid-philtrum) of a 50-59 aged male can use the landmarks comes under the factor 1 – Supra orbital, Glabella, Nasion, End of nasal bone, Upper lip margin, Mid-philtrum and create the regression tree to find Upper lip margin and Mid-philtrum and get the most appropriate values for those according to the values of other four known landmarks.

The results of the applied random forest analysis method shows that more accurate and similar values can be gained for the missing tissue thicknesses than using the regression tree analysis method. So it is possible to conclude that by using random forest regression it is able to get more accurate values than using the regression tree analysis method.

5.3. Drawbacks and Problems Experienced

5.3.1. Identification of Landmarks

The landmarks and measurements chosen for this study were previously used by researchers namely Peter et al [20], Bulut O. et al[18] and De Greef S. et al[21] in their research work. Also all these landmarks were used in the early stages of this research. Although careful consideration was given when choosing the landmarks and measurements, there was still some difficulty with the identification or location of several landmarks on the 2D views of MRI scans.

A particular MRI sample contains a set of slides in sagittal, axial and coronal views. Since data was only obtained from established clinical databases (not specifically for this research) the alignment of the image varies from case to case. This was due to the different positioning of the skull of the patient. As a result some landmarks were not visible in particular cases.

Also when taking MRI scans normally jaw area is not captured (Because brain MRIs are used to identify the disorders related to the brain). As a result landmarks around the jaw area were not visible in most of the cases.

Clarity of some samples was not in the desired level to get the measurements. Canny edge detection was applied using Matlab software for those samples.

Few discrepant samples were discarded due to these reasons.

5.3.2. Measurement of FSTT

In the early stages of this research which used CT images to perform the analysis measurements were performed from 3D model of the skull generated through CT images. When it comes to MRIs, with the analysis of literature no suitable technique was found to construct 3D images. When plotting landmarks from a 3D model generated from CT images one corresponding

landmark on the 3D surface of the skull was plotted automatically on the 2D surface so that measurements can be performed on the 2D surface.

But, when taking measurements from MRIs, measurements were solely performed on the 2D surface using Radiant DICOM Viewer software. Locating landmarks on the 2D surface had to be done manually being a hectic process. Sometimes the correct position of the landmark was misidentified and this reason leads to the measurement of tissue thickness at incorrect position.

5.3.3. Insufficient Sample Size

All the samples collected were divided into age-gender categories and statistical analyses were done based on the samples in each age -gender group. With the discard of few samples some categories did not contain the required minimum number of 30 samples to carry out certain statistical tests. In that case there's a certain effect on the validity of the test results. Few number of random data was generated using R statistical software for the discrepant samples.

Hence it is vital to have sufficient number of samples in order to run statistical analysis and establish correct findings.

5.3.4. Unavailability of Published Raw Data for Interpolation from Foreign Studies

As mentioned in the design chapter statistical interpolation was to be performed using FSTT values of foreign studies. But, none of the 3 foreign studies selected contain raw data or contain any information regarding the normality of the samples. Though raw data was requested from the authors of the three studies no response received up until the date of writing this thesis. Also, it was unable to find other foreign studies which contained published raw data.

Normality of the samples should be known in order to perform statistical analysis. Raw data is needed in order to calculate the normality of the samples as well as to plot the distribution of FSTT values of the samples and measure whether there exists a closer relationship with the Sri Lankan population.

Therefore, all the statistical analyses were only performed from the available mean FSTT values of the three populations.

5.3.5. Limited Time Period for the Development of the FSTT Model

For the measurement of FSTT at 23 landmarks of more than 200 samples it consumed couple of months than we expected. However statistical analysis of the data was completed.
But most of the statistical models mentioned in the literature are mathematical equations which need higher Mathematical background to understand. Moderately high learning curve was needed to study the Mathematical background needed to produce equations for the trend analysis curves. With the time constraints mathematical study was not done hence the model building was not completed. With the results of the learning methods established through this study and study of mathematical models, this research indulges another research study to complete the FSTT model.

5.4. How to Use the Results of this Study

The results obtained in the current study represent the facial soft tissue thicknesses for adult population group (20-59 years of age) of Sri Lanka for facial reconstruction purposes. No other similar study has been conducted in Sri Lanka in which the soft tissues of the faces of Sri Lankan adults have been measured except the pilot study conducted as an early stage of this research.

Facial reconstruction from the skull can be a sophisticated process, since there are a wide variety of human faces, and although the skull gives much detail on the overlying features, it will never give a hundred percent accurate estimation of what the features should actually look like. The FSTT measurements were used as guidelines to the depth of the tissues overlying specific landmarks. This study has established population-specific tissue thickness values for Sri Lankan adult population within the age category 20-59 years, therefore these data are for use on a skull of an individual who belongs to this same population group. Thus, these data could be used in the instances of Forensic facial Reconstruction, Facial Sculpting and Plastic surgeries purposes.

These values are only mean measurements that represent average face. Since the average measurements were used, the FSTT measurements may sometimes underestimate or overestimate true facial dimensions of some individuals. Regression tree analysis was done to overcome this issue. More specific FSTT measurements for unknown set of landmarks of an individual could be obtained with a set of possible guesses of FSTT values of Landmarks on the reconstructor's hand by using the learning methods explored through this research.(e.g- during an instance where the generalized mean values presented through this study does not fit a particular case)

Chapter 6 - Conclusion and Future Work

6.1 Conclusion

Having a common reliable reference of FSTT in the process of forensic facial reconstruction, facial sculpting and plastic surgery purposes is utmost important in the context of Sri Lanka. Facial approximations for male and female populations of the 20-59 age groups were explored through this research. All the landmarks used in this research are defined in forensic anthropology and all the measurements were taken under the supervision of the experts of the field. The reliability and the reproducibility of the measurements were successfully evaluated in terms of statistical methods.

The research has presented the basic descriptive statistics for each age group and has evaluated the significance of FSTT measurements within age and gender groups of the Sri Lankan population. A comparison of the current study with three other published foreign studies was performed to evaluate which foreign study shows closer relationship with the Sri Lankan study. All the analysis was performed based on statistical methods.

Statistical analyses and learning methods were performed to interpolate missing values for the purpose of having more customized and reliable FSTT values which was one of the major concerns of the second objective of the research. A case was reconstructed based on the interpolated values (mentioned under the second objective) accomplishing the third objective.

Although the analysis was performed only for the 20-59 age category due to unavailability of sufficient samples, this process would also be scalable to any other age groups (below 20 and 60 and above)on the persistence of data. Further analysis can be conducted to evaluate the effect of the weight factor on the FSTT with the availability of weight details of patients. Ultimately, with further analysis of more number of samples the results of the FSTT database can be taken into the use in national level.

6.2. Future Work

6.2.1. Conduct a Facial Component Analysis for all the age ranges of the Sri Lankan population

To reconstruct a more precise and personalised facial model it is important to analyse the facial features namely eyes, mouth, nose, eyebrows etc.

In the early stages of this research the researchers have focused on the facial component analysis of eyes and nose within the age group of 25 – 30, male/female with regard to the Sri Lankan context. Another study also has been conducted with regard to Facial Index Based 2D Facial Composite Process for Forensic Investigation in Sri Lanka [60]. This study has provided a system to the law enforcement agencies for the purpose of carrying out an efficient and effective facial composite process. Further research can be conducted in this area to produce more accurate facial structure. Results of these kinds of analyses could be used in more reliable suspect identification activities.

6.2.2. Conduct a full analysis of the Facial Soft tissue Thickness by considering the BMI factor

The FSTT of a particular person varies with the age, gender as well with the height and weight. However, those factors (height and weight) were not considered in this research as height and weight data were not available with the clinical MRI samples obtained. Other published studies for foreign populations have conducted analysis with regard to the variation of the FSTT against the BMI value by collecting data from patients specially for their research work.

Therefore, with the persistence of height and weight data further analysis can be conducted to check the effect of the BMI for the variability of the FSTT.

6.2.3. Interpolation of missing Sri Lankan FSTT values

Due to the unavailability of sufficient samples for statistical interpolation, missing FSTT values of Sri Lankan sample could not be found. Yet, this research has found that FSTTs of Taiwanese population show closer relationship with the FSTTs of the Sri Lankan population with statistical tests and graphical representation methods.

The validity of this ground finding can further be explored by conducting statistical analysis with raw data samples and genetic experiments. If claim is valid based on the pattern of FSTT

variation between 2 population groups, missing FSTT values of particular landmarks can be interpolated using statistical interpolation methods.
With the persistence of raw data for each age category normality of the samples can also be assessed (In this research it was assumed that the foreign samples are normally distributed).

In addition, the results of the principal component analysis (PCA) of 40-49 and 50-59 age ranges of current study show that components are encompassed with similar landmarks. According to the above finding, in order to predict the missing data values of one age range, it is applicable to use available data of another age range. This can be done through a neural network based approach through another research. The lack of sufficient training and testing data samples restricted the ability of applying a neural network for above purpose within the current study.

6.2.4. Develop a complete national level FSTT database

As the first objective of this research a database was constructed by including all the average tissue thickness values. However, missing FSTT values of particular landmarks were not included in it. Also, age ranges such as below 20 years and 60 years and above were not included in the scope of this research. After the interpolation of missing values and developing FSTT values for the mentioned two age ranges a completed FSTT database can be developed including the already established data through this research.
This final database could be used in national level for facial reconstruction purposes.

6.2.5. Develop a Unified FSTT model for the Sri Lankan adult population

One of the main objectives of this research is to assess the possibility of developing a unified FSTT model for the Sri Lankan context using statistical analysis and learning methods. The results of the statistical analysis and learning methods explored through this research indulges to produce a FSTT model as another research work.

6.2.6. Develop a software tool by integrating the FSTT model

A novel software tool can be developed by integrating the FSTT model developed (section 6.2.5). This tool must aid the user in giving the output FSTT values according to the user input age and gender. Depending on the user requirement the tool must give a personalised or generalized FSTT (average FSTT value) output for a given Landmark through user friendly Graphical user

Interfaces. The developed FSTT database and the FSTT model should integrate and collaborated to give the output to the user.

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Appendix

Appendix A

Normality Tests

#Installing the libraries and reading the data file

```
install.packages("dplyr")
install.packages("ggpubr")
library("dplyr")
library("ggpubr")
my_data <- read.csv(file.choose())
```

#Q-Q plot

```
ggqqplot(my_data$LM)
```

#Shapiro-Wilk's method

```
shapiro.test(my_data$LM)
```

#Anderson - Darling test

```
install.packages("nortest")
library(nortest)
ad.test(my_data$LM)
```

#Jarque-Bera test

```
install.packages("tseries")
library(tseries)
jarque.bera.test(my_data$LM)
```

Appendix B

PCA

#read data

```
data<-read.table(file.choose(),header=TRUE,sep=",")
```

#Show the head part of the loaded data set including available variables.

```
head(data)
```

#Run PCA

```
data.pca<-princomp(data)
```

#Generating the summary resulted by the PCA

```
summary(data.pca)
```

#Generate the scree plot to determine the number of factors to retain

```
screeplot(data.pca, type = “lines”)
```

#Factor analysis

```
data.fa<-factanal(data, factors=4, rotation="varimax",scores="regression")
head(data.fa$scores)
```

#Print the sorted results (up to four decimal places) of the factor analysis greater than 0.4

```
print(data.fa, digits=4, cutoff=0.4, sort="TRUE")
```

Appendix C

Regression Tree

 # Installing the libraries and reading the data file

```
install.packages("rpart")
install.packages("rpart.plot")
library(rpart)
library(rpart.plot)
my_data <- read.csv(file.choose())
str(my_data)
```

#Creating a subset of the data set

```
df<-my_data[,c(1,2,3,4,5,6)]
str(df)
head(df)
m1 <-rpart(Mid.philtrum~.,data=df,method='anova')
m1
```

#Plotting the regression tree

```
rpart.plot(m1,type=3, digits=3,fallen.leave=TRUE)
```

Appendix D

Random forest analysis

```
install.packages('randomForest')
library(randomForest)
my_data <- read.csv(file.choose())

names<-c('Age')
my_data[,names]<-lapply(my_data[,names], factor)
str(my_data)

train <- my_data[1:38,]
test<-my_data[1+39:62,]

rf <- randomForest(Supra_glenoid~ Zygomatic_arch + Jugale+ Infra_orbitale+ Ectoconchion + Age,
data=train, importance=TRUE, proximity=TRUE, ntree=1000)
 print(rf)

my_prediction <- predict(my_forest, test)

my_solution <- data.frame(Age = test$Age, Zygomatic_arch=test$Zygomatic_arch,
Jugale=test$Jugale, Infra_orbitale=test$Infra_orbitale, Ectoconchion=test$Ectoconchion ,
Supra_glenoid = my_prediction)

print(my_solution)

importance(my_forest)
varImpPlot(my_forest)
MAE(train$Supra_glenoid, p1)
MAE(test$Supra_glenoid, p1)

 mae<-function(error)
+ {mean(abs(error))}
```

```
 mae<-function(error)
+  {mean(abs(actual))}
actual<-c(actual)
predicted<-c()
error<-(actual-predicted)
rmse(error)
mae(error)

mape<-function(error)
+ {mean(abs(error/actual)*100)}
```

Appendix E

Images for Measurements of landmarks using multiple views of MRI

1. **Bregma**

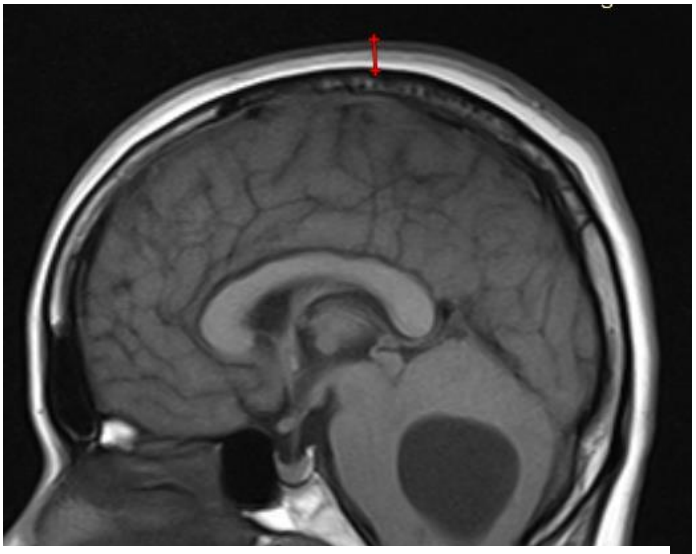

Figure 7.1- Position of the Bregma from the sagittal view

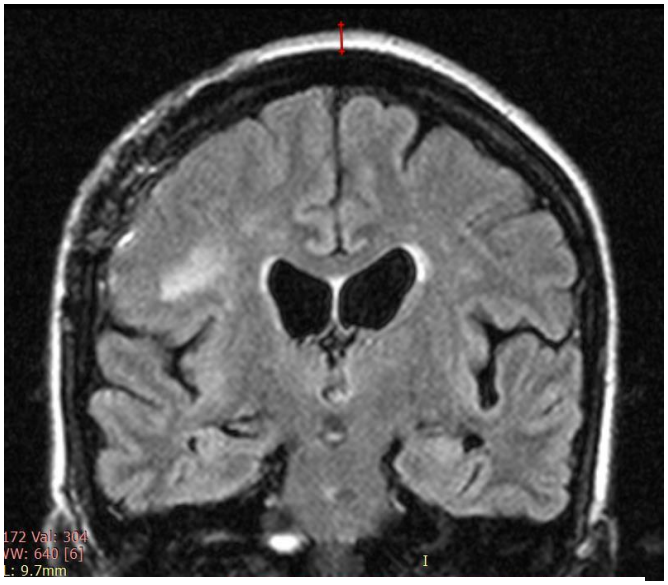

Figure 7.2- Position of the Bregma from the Coronal view

2.Glabella

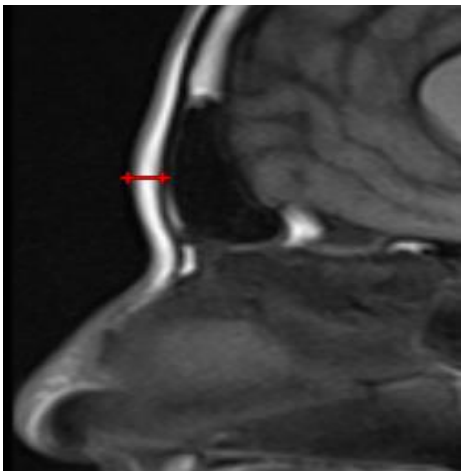

Figure 7.3-Position of the **Glabella** from the Axial view

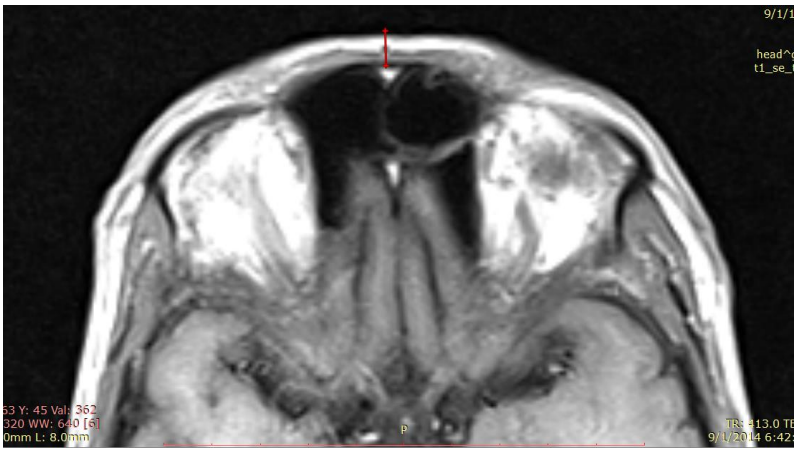

Figure 7.4 - Position of the from the **Glabella** sagittal view

3. Nasion

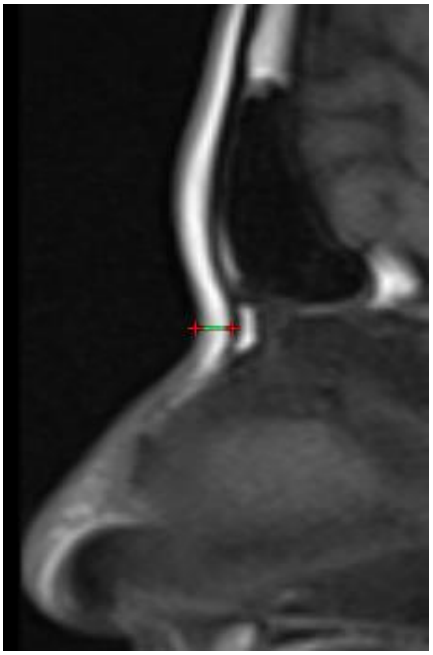

Figure 7.5 - Position of the Nasion from the Sagittal view

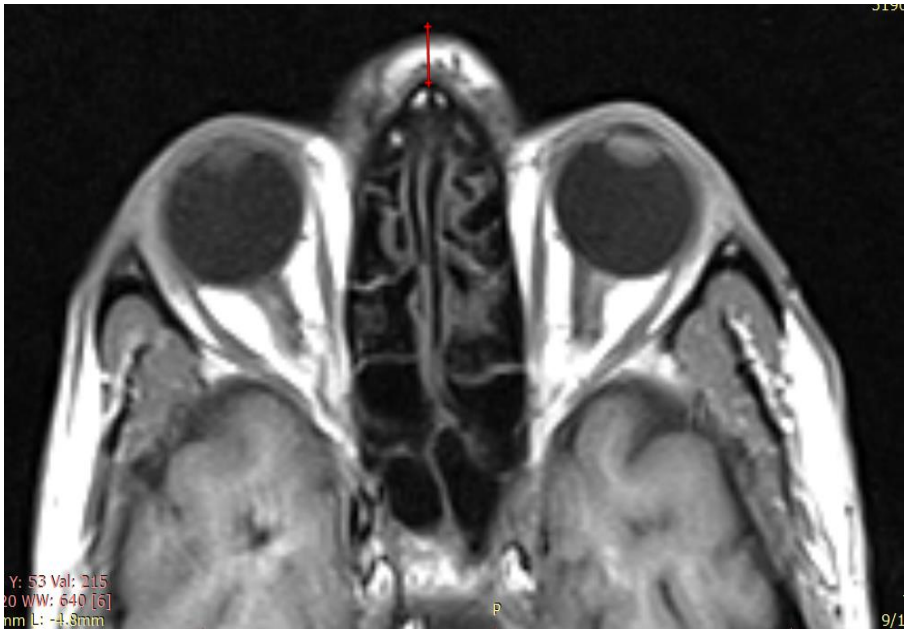

Figure 7.6 - Position of the **Nasion** from the Axial view

4. End of nasal bone

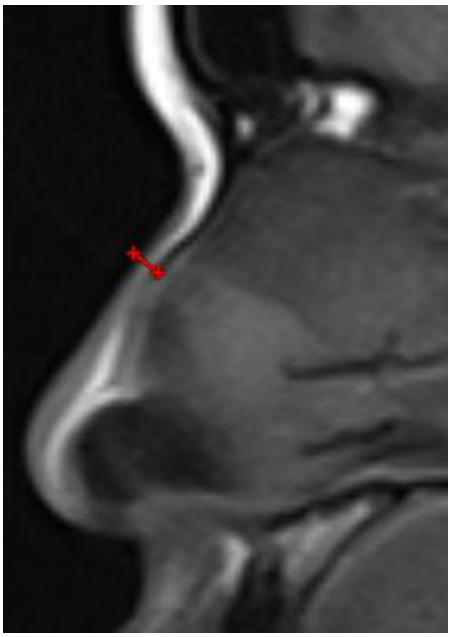

Figure 7.7 - Position of the **Nasal bone** from the sagittal view

5. Mid philtrum

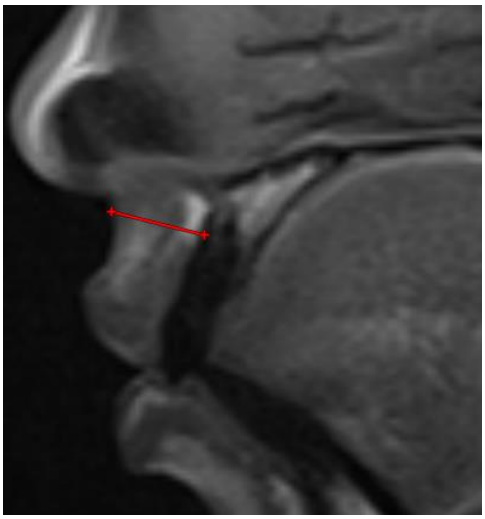

Figure 7.8 - Position of the **Mid philtrum** sagittal view from the sagittal view

6. Upper lip margin

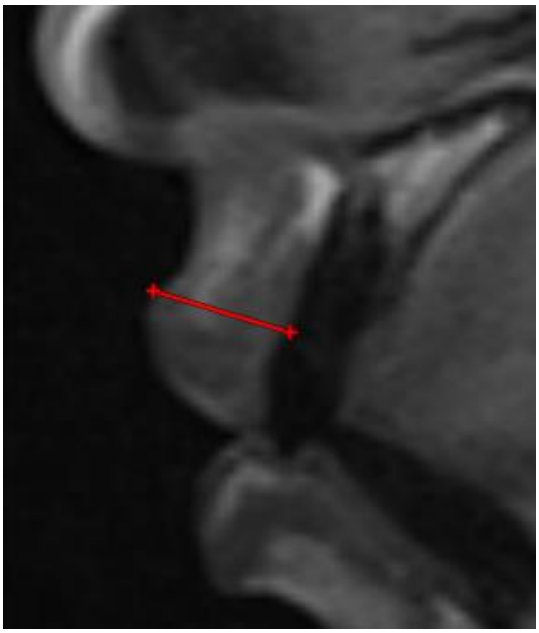

Figure 7.9 - Position of the **Upper lip margin**

7. Lower lip margin

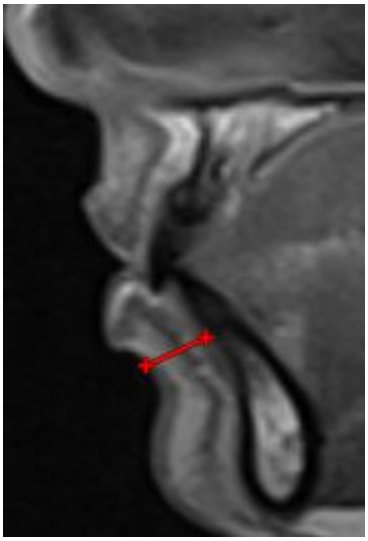

Figure 7.10 - Position of the **lower lip margin** from the sagittal view

8. Chin-lip fold

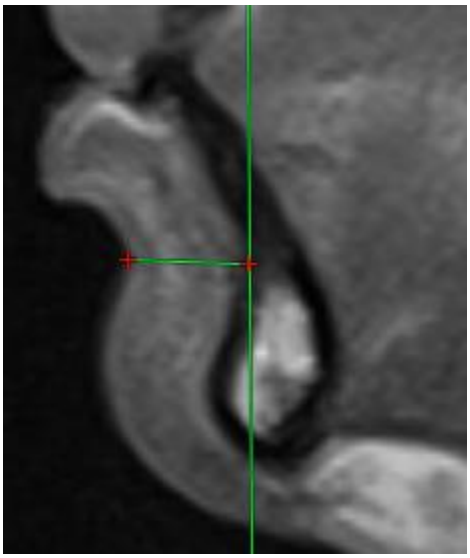

Figure 7.11 - Position of the **chin-lip fold** from the sagittal view

9. Mental eminence

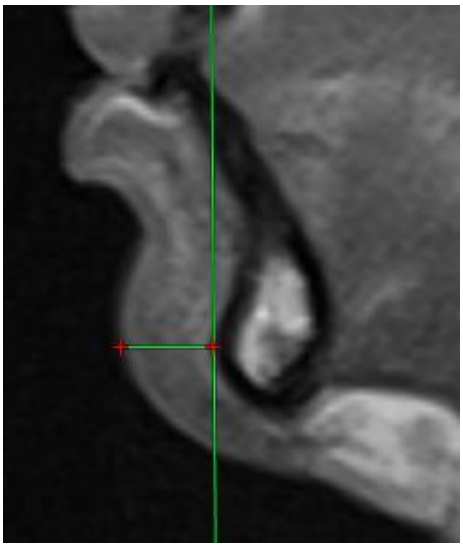

Figure 7.12 - Position of the **Mental eminence** from the **sagittal** view

10. Beneath chin

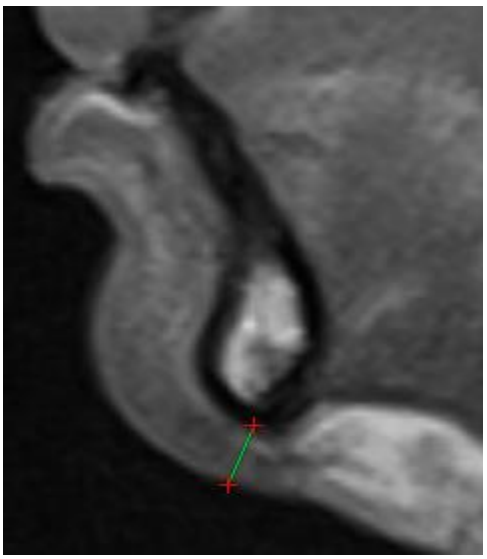

Figure 7.13 - Position of the **Beneath chin** from

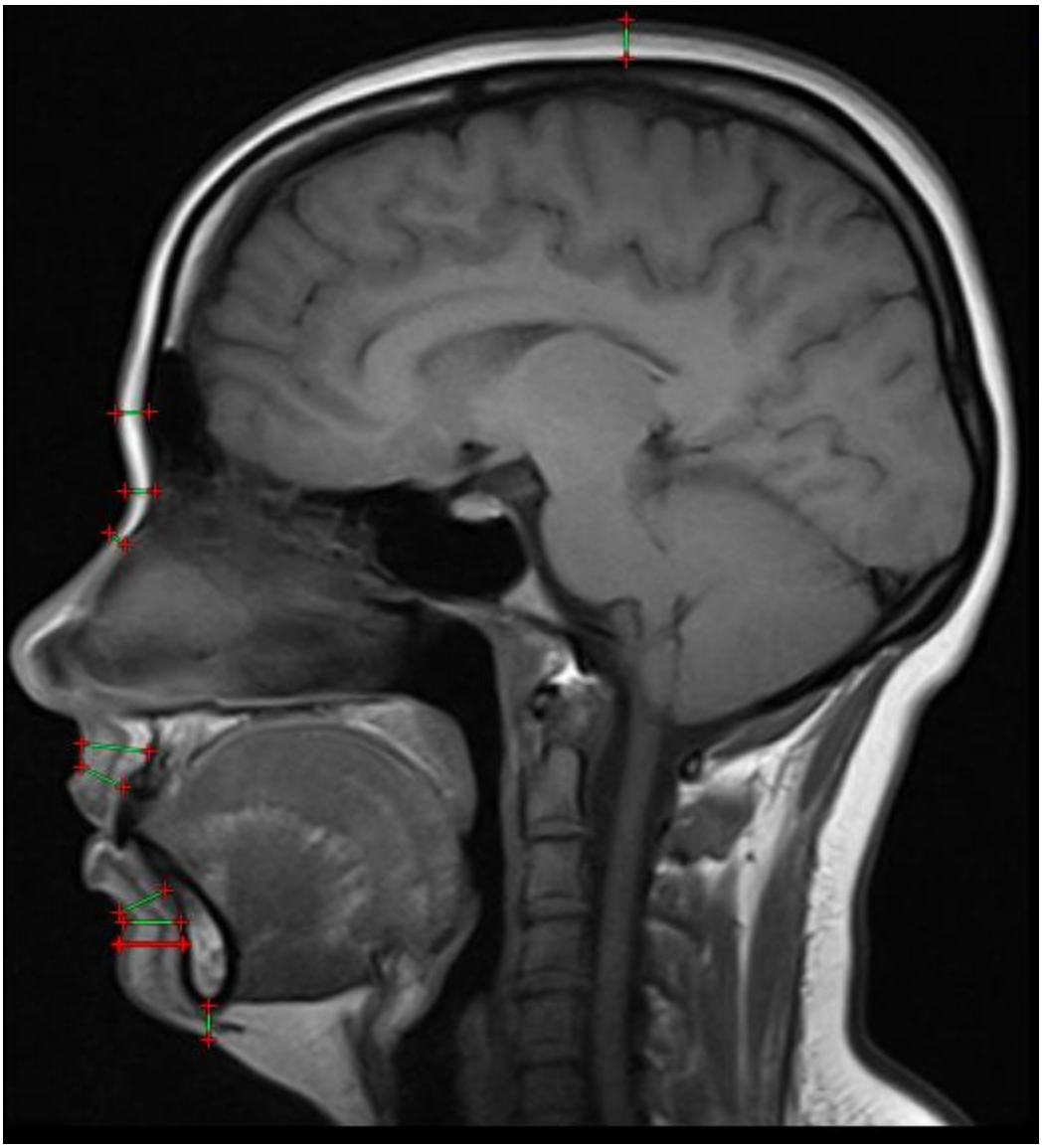

Figure 7.14 - Position of the **midline landmarks** on the sagittal view

11. Supra-orbital

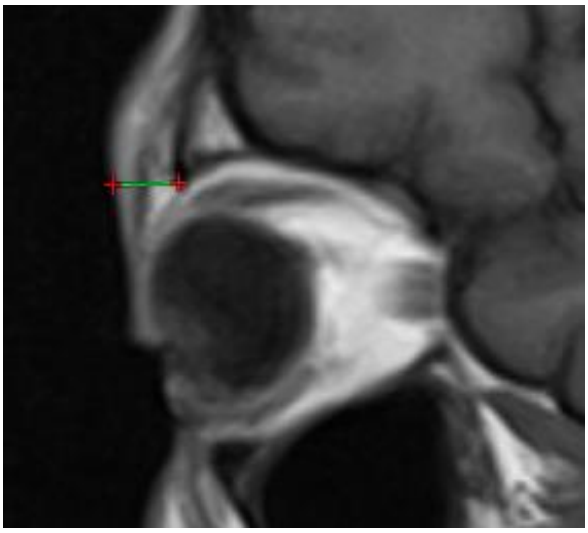

Figure 7.13 - Position of the **Supra- orbital** from the sagittal view

12. Infra orbital

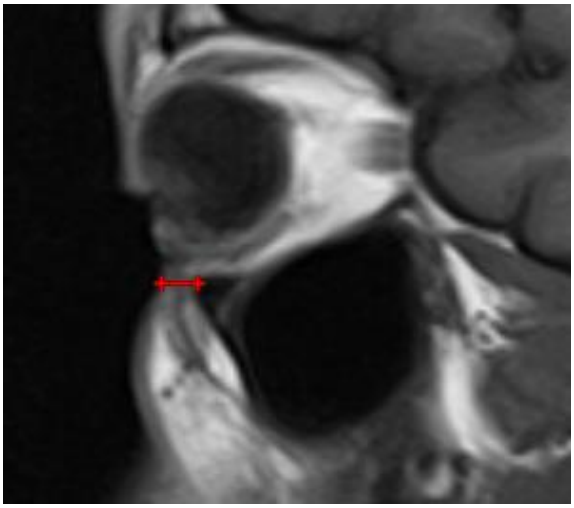

Figure 7.17 - Position of the **Infra-orbital** from the sagittal view

13. Ectoconchion

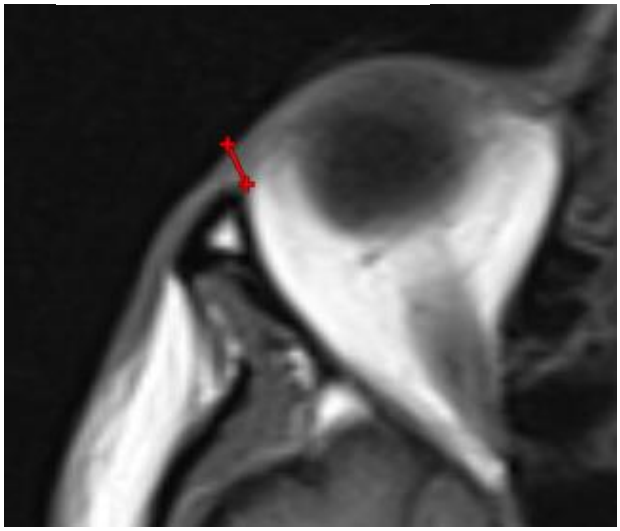

Figure 7.16 - Position of the **Ectoconchion** from the sagittal view

15. Supra-canine

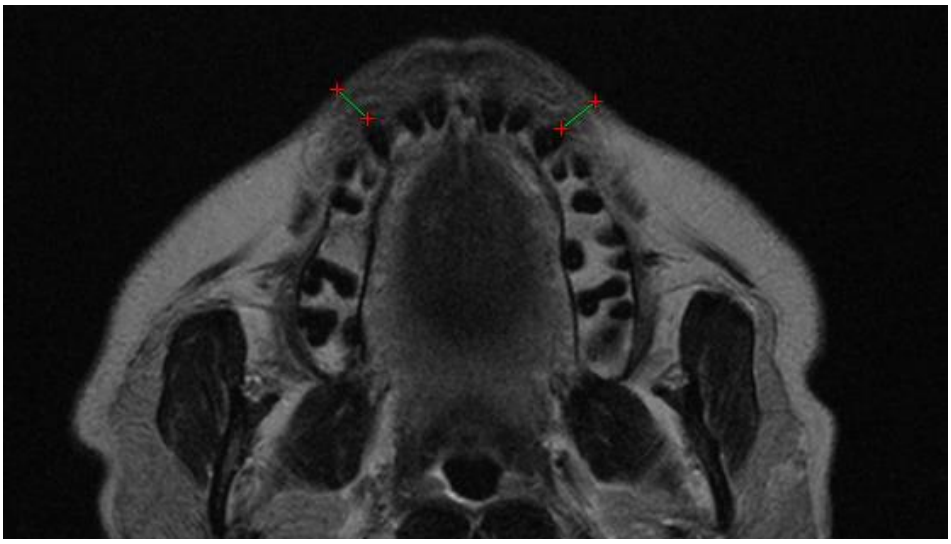

Figure 7.18 -Position of the **Supra-canine** from the axial view

16. Infra canine (Volume MRI)

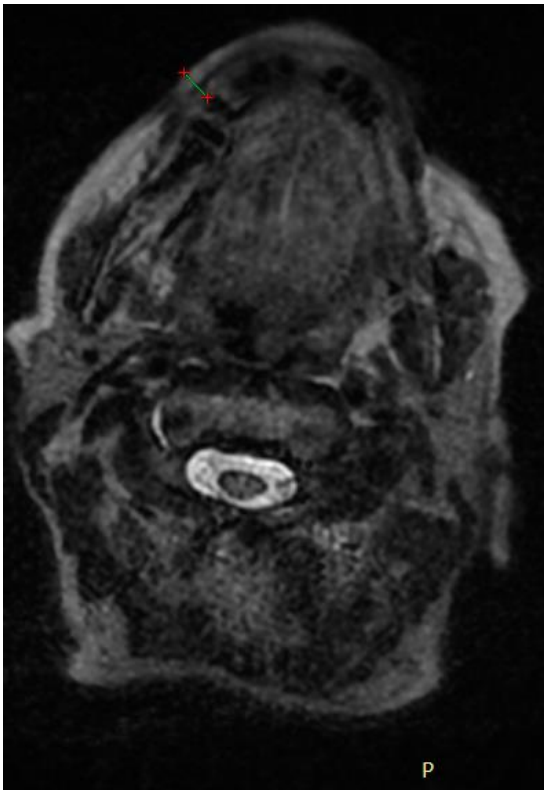

Figure 7.19 -Position of the **infra-canine** from the axial view

17. Jugale

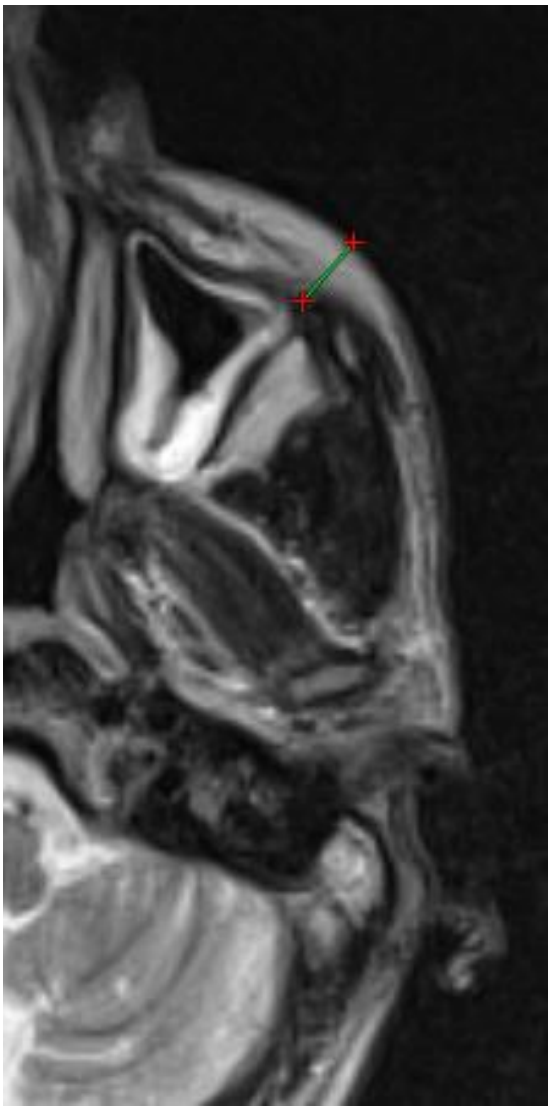

Figure 7.20 -Position of the **Jugale** from the axial view

18. Zygomatic arch

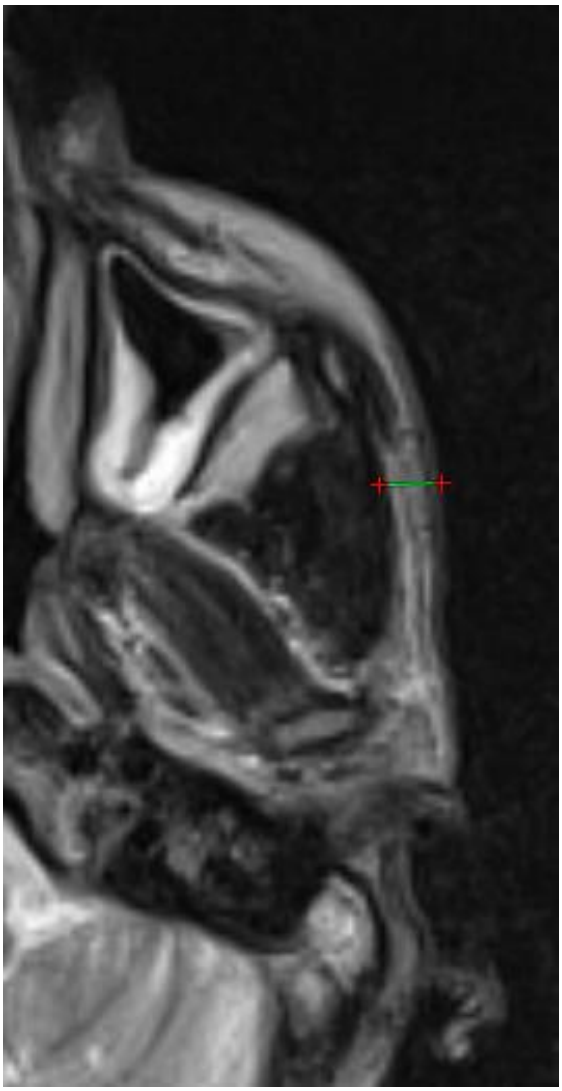

Figure 7.21 -Position of the **Zygomatic arch** from the axial view

19. Supra glenoid

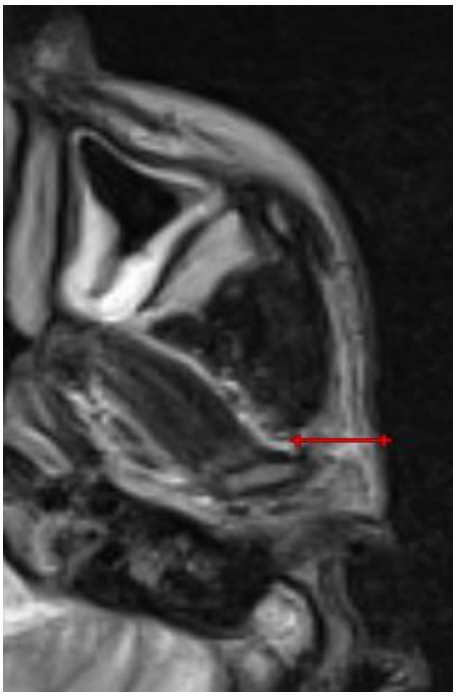

Figure 7.22 -Position of the **Supra glenoid** from the axial view

20. Mastoidale

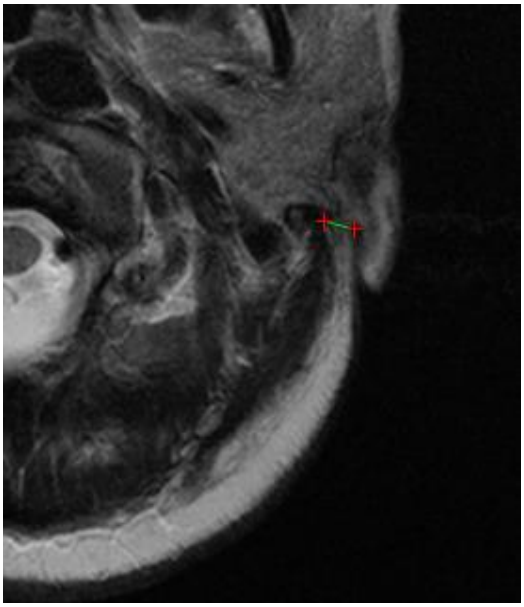

Figure 7.24 -Position of the **Mastoidale** from the axial view

25. Euryon

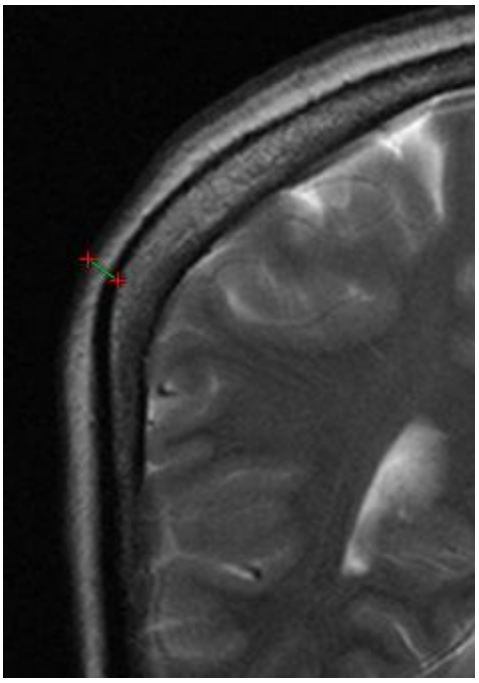

Figure 7.23 -Position of the **Euryon** from the sagittal view

30. Gonion

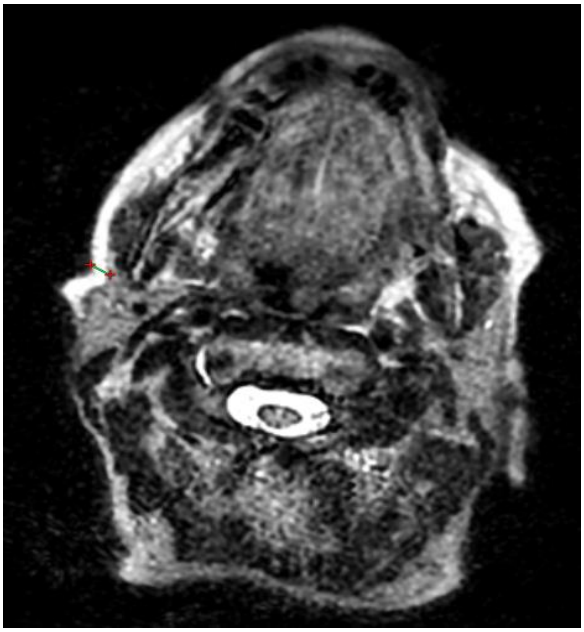

Figure 7.25 -Position of the **Gonion** from the sagittal view