THUMBPRINT, FACIAL ANTHROPOMETRY AND BODY MASS INDEX IN HAUSA ETHNIC GROUP OF KANO STATE, NIGERIA

BY

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DECLARATION

I, Lawan Hassan ADAMU hereby declare that the work in this thesis titled "***Thumbprint, Facial Anthropometry and Body Mass Index of Hausa Ethnic Group in Kano State, Nigeria***" was performed by me in the department of Human Anatomy, Faculty of Medicine, ABU, Zaria, under the supervision of Prof. S. A. Ojo, Dr. B. Danborno and Prof. S. S. Adebisi.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for other degree at any institution.

Lawan Hassan ADAMU	Signature	Date

CERTIFICATION

This thesis entitled "***Thumbprint, Facial Anthropometry and Body Mass Index of Hausa Ethnic Group of Kano State, Nigeria***" by Lawan Hassan ADAMU, meets the regulation governing the award of Doctor of Philosophy (Ph.D.) degree in Department of Human Anatomy, Faculty of Medicine, Ahmadu Bello University, Zaria, under the supervision of Prof. S. A. Ojo, Dr. B. Danborno, and Prof. S. S. Adebisi. It is, therefore, approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to Almighty **ALLAH**. His mercy, love, and comfort are incomparable. Also to our noble prophet **MUHAMMAD** (SAW), his companions and those who follow his right path to the day of resurrection.

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LIST OF ABBREVIATION

A: Asymmetry

AA: Absolute asymmetry

Al: Alar

AM: Average measures

AMA: Aperture modified angle

ANOVA: Analyses of variance

AS: Antisymmetry

B: Bifurcation

BLR : Binary logistic regression

BMI : Body mass index

C: Convergence

CA: Composited asymmetry

Ch: Cheilion

CJWR: Cheekbone to jaw width,

DA: Directional asymmetry

DF: Degree of freedom

Dpi: Dot per inch

En: Endocanthion

ES: Eye size

Ex: Exocanthion

F: Frequency

FA: Fluctuating asymmetry

FE: Fisher’s exact

FH I: Forehead height I

FH II: Forehead height II

FTIR: Frustrated total internal reflection

FW/LFH: Face width to lower face height ratio

Gn: Gnathion

Go: Gonion

HC: Height of calva,

ICC: Intraclass correlation

IOD: Interocular distance

LF/FH: Lower face to face height ratio

LFH: Lower facial height

Li: Labiale inferius

Ls: Labiale superius

MCA: Mentocervical,

MEH: Mean of eyebrow height

MSI: Multispectral Fingerprint Imaging

MW: Mouth width

N: Nasion

NA: Nasion angle

NFcA: Naso-facial angle

NFrA: Naso-frontal angle

NMA: Naso-mental angles

NW: Nasal width

OL: Orbital length

PAR : Perimeter to area ratio

Pi: Palpebrale inferius

PRC: Proximal ridge count

PRPC: Proximal ridge pore count

Ps: Palpebrale superius

R: Ridge

RD: Ridge density

ROC: Receiver operating characteristic

RRC: Radial ridge count

RT: Ridge thickness

SA: Signed asymmetry

SD: Standard deviation

SFH: Special face height

SHH: Special head height

SM: Single measures

SMARCAD 1: SWI/SNF-related matrix-associated actindependent regulator of chromatin subfamily A containing DEAD/H box 1

Sn: Subnasale

Sto: Stomium

SUFH I: Special upper face height I

TEM: Technical error of method

Tr: Trichion

UFH: Upper facial height

UFW: Upper facial width

URC: Ulnar ride count

V: Vertex

VAV: Variable average value

WHR: Width to upper facial height ratio,

WTR: Waist circumferences to hip ratio

Zy: Zygon

ABSTRACT

Exploration of human variation using dermatoglyphics and facial features has long been considered as an important marker within the domain of biological anthropology. The aim of the study was to discriminate sexes using thumbprint and facial profiles, and also to determine asymmetry and the relationship between facial profiles with thumbprint profile and body mass index in Hausas of Kano State, Nigeria. A total of 534 participants, comprising 398 male and 136 females participated. Direct sensing fingerprint capturing method was used to obtain the fingerprints. Ridge density, thickness, and pores, counts were determined within a 25 mm^2 area. Using photometric methods, 19 unpaired, four paired dimensions, and six facial angles were measured. Three indices of fluctuating asymmetry were calculated. Chi-square test, independent sample t-test, Pearson's correlation, multiple and binary logistic regression and receiver operating characteristic curve were used. The results showed that there was no statistically significant association between sex and pattern of thumbprints. The ulna ridge density of male (10.01 ± 1.31) was significantly ($P < 0.05$) lower than that of females (10.91 ± 1.69) in the right thumb. The ridge thickness had inverse relation with ridge density. Pores count in the proximal the right thumb were significantly different ($P < 0.05$) between males (55 ± 7.96) and females (63 ± 6.91). It was shown that right ulna ridge count was the single best variable to discriminate sex (with 63.4% accuracy). For the left thumbprints, the proximal ridge thickness discriminates sex better (62.8% accuracy). Sexual dimorphism was observed in mean minutiae count. In the two minutiae, ridge return (0.09 ± 0.32 against 0.001 ± 0.001) and ridge convergence (1.98 ± 2.00 against 1.17 ± 1.34) females have higher mean in left thumbprints. Ridge break (with 66.4% accuracy) and ridge end (65.4% accuracy) were the

single best sex discriminator in right and left thumb, respectively. Upper facial height (76.2% accuracy) was the best discriminator of sex. Only nasomental (70.3% accuracy)angle indicate a good probability of prediction. Significant differences ($p < 0.05$) in signed asymmetry occurred in bifurcation, cross-bar, break, bridge, point/dot into ridges and point/dot between the ridges. In most of the minutiae types, males tend to have significantly higher ($P < 0.05$) mean values. In facial dimension, a significant difference ($P < 0.05$) was observed. Facial proportion analyses show no occurrence of classical canon in both sexes. There was also no significant ($P < 0.05$) association between sexes invariant of the canon. Body mass index correlated with most the linear facial dimensions. Similarly, lower facial width was the single best predictor (males; $R^2=8.8$, females; $R^2=0.26$, $P < 0.05$) of body mass index. Radial ridge thickness and enclosure (small) were the best predictiors of body mass index in males and females respectively. In conclusion, a linear relationship between thumbprint and the facial profile was established. Facial profiles were the predictors of the body mass index, compared to the thumbprint profiles among Hausas of Kano State, Nigeria.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Determination of individual variation using dermatoglyphic features has long been considered as a useful marker within the domain of biological anthropology (Reddy *et al.*, 2000, Karmakar *et al.*, 2006; Siváková *et al.*, 2007; Karmakar *et al.*, 2008; Adebisi, 2008; Adebisi, 2009a). In the case of faces, the situation is very similar to dermatoglyphics (fingerprints) (Cummins and Midlo, 1961). Human fingers are known to display friction ridge skin (FRS) that consists of a series of ridges and furrows, generally referred to as fingerprints. Fingerprint friction ridge details are described in a hierarchical order ranging from level zero to three, mainly based on resolutions (Jain *et al.*, 2007).

Each of the levels reveals different categories of the fingerprint features. Level zero (texture) is for revealing localized textural pattern only which is achieved under ~50 dpi. Level one (pattern) is for revealing macro detail such as ridge flow and pattern type which is achieved under ~250 dpi. Level two (points) is the Galton characteristics, or minutiae points, such as Bifurcations and endings which is also achieved under ~250 dpi. Level three (shape) includes all dimensional attributes of a ridge, such as ridge path deviation, width, shape, pores, edge contour, incipient ridges, breaks, creases, scars, and other permanent details which is achieved under ~1000 dpi (Hong *et al.*, 1998; Jain *et al.*, 2007). However, unique characteristics of individual fingerprint will be more appreciated from level one (~ 250 dpi) through level three (~ 1000 dpi). This brings the need for assessing fingerprints

right from pattern type, minutiae points and other associated features and characteristics of the ridges such as ridge density, thickness and pore (Jain *et al.,* 1997; Jain *et al.,* 2007).

There are three basic patterns of fingerprints these include, arches: the ridges enter from one side of the finger, rise in the center forming an arc, and then exit the side of the finger. Loop: the ridge enters from one side of a finger, form a curve and tend to exit from the same side they entered from. Whorl: the ridges form circularly around a central point on the finger (Ashbaugh, 1999; Langerberg, 2005; Jain *et al*., 2007).

The second feature of interest is fingerprint minutiae, a term coined by Galton, to refers to the small distinguishing features associated with the individual ridge, show great variability in different population constituting the basis for identification of fingerprint impressions in the field of forensic sciences (Gutie´rrez-Redomero *et al.*, 2007). The varieties of the minutiae or characteristic points reported in the literature include; ridge ending; a termination of a ridge, bifurcation; when the minutiae form ridges to the right, convergence; when the minutiae form ridges to the left, fragment; short ridge with length equal or less ten times its width, point or dot; one ridge unit which contains only one sweat gland pore, break; two ends of ridge very near and opposite, enclosure; where the ridge path divides and then comes together again, overlap; where two ridge ends meet and overlap on a bias, crossbar; ridge that separates from its direction crossing between two others, bridge or crossover; where a short ridge crosses from one ridge to join the next, opposite bifurcations; two ridges that join at one point, Y or M; when two bifurcations

develop next to each other on the same ridge a unique formation, dock; crest end that enters between two other end ridges, and return; the turning around of a ridge without being part of the nucleus (Champod, 1996; Gutie´rrez-Redomero *et al.*, 2007).

Another ridge feature which is close to ridge minutiae is ridge pores. The earlier forensic utility of ridge pore was seen in the study of ridges by Locard, in 1912, which observed 9 to 18 pores per centimeter of the ridge. It was suggested that 20 to 40 pores should be sufficient to establishidentity (Ashbaugh, 1999). It was reported that size, shape, position, and a number of pores on the ridges are individualistic and useful in personal identification (Nickell and Fischer, 1999; Ashbaugh, 1999).Based on the position on the ridges, pores are often divided into two categories: open and closed. A closed pore is entirely enclosed by a ridge, while an open pore intersects with the valley lying between two ridges (Kryszczuk *et al*., 2004).

Human identification could also be achieved by anthropometric methods such as the epidermal ridges anthropometry where ridge breadth are measured by a forensic anthropologist for such purpose. The true breadth of a ridge is the distance between the center of one epidermal furrow and the center of the next furrow along a line at right angle to the direction of the furrows (Penrose, 1968; Kamp *et al.*, 1999). Additionally, the number of ridges per linear unit enables the estimation of the breadth of the ridge by dividing the linear unit by the number of ridges (Cummins *et al*., 1941; Ohler and Cummins, 1942; Gutiérrez-Redomero *et al*., 2011). Hecht was the first to report on ridge

breadth growth; however, the extensive literature on epidermal ridge breadth was achieved by Cummins and co-workers (Kamp *et al.,* 1999).Some dectelocopists have taken new dimension in the study of ridge breadth by studying a ridge density per square area to further establish the individual variation in fingerprints features (Nayak *et al.,* 2010; Nithin *et al.,* 2011; Krishan *et al.*, 2012; Gutiérrez-Redomero *et al.*, 2013; Eshak *et al.*, 2013).

Another important and interesting aspect of human characterization and identification is a facial assessment. This is one of the field of biological anthropology which gained acceptance with the emerging science of biometrics in the forensic sciences and other related scenarios such as combat of terrorism, illegal immigration, and any means of personal identification (Gibellia*et al.,* 2012). The facial trait of an individual has been defined as the soft tissues of the face together with the underlying bony skeleton. The traits are the main indicative feature in physical appearance, which is always associated with social acceptance, psychological well-being, and self-esteem of an individual (Hershon and Giddon, 1980; Sahin and Gazileri, 2001).

The anthropometric assessment, such as linear dimensions of specific facial regions has also been investigated for personal identity and can serve as a way of revealing information with respect to the biological profile; ancestry, sex, the age of an individual. It was reported that the role of such metric assessment in forensic sciences has been questioned by another investigator (Kleinberg *et al*., 2007). Different technologies were used in the past decade for metric characteristics of human faces (Ferrario *et al*., 1995; Jeffries *et al*., 1995; Ferrario

and Sforza, 1996; Ventura *et al*., 2004; Sforza, *et al*., 2004; De Angelis *et al*., 2009). Ethnic variation in the facial profile necessitates the need for an ethnic-specific facial model in order to accommodate various fields of application such as plastic (both cosmetic and reconstructive) and orthodontic surgery (Porter and Olson, 2001; Porter, 2004).

For forensic purpose relatively few studies have considered facial assessment, although a promising result has been obtained especially in the field of age estimation of the living (Ferrario *et al*., 2000; Ferrario *et al*., 2003), defining sexual dimorphism (Ferrario *et al*., 1995), and traits specific to ethnic groups (Le *et al*., 2002; Porter, 2004; Farkas *et al*., 2007; Roelofse *et al*., 2008). It was generally accepted that facial traits may be extremely useful if used with caution for aging, sexing, determining ancestry and even in the initial phases of personal identification within the forensic domain (Ritz-Timme *et al*., 2011).

To explore more of facial trait there is need to analyze the facial features like angles which are formed by the point of intersection of the linear dimension. It was reported that not all facial traits directly follow the underlying dentoskeletal profile, therefore extensive evaluation of facial angles are essential in soft tissue facial profiling (Subtenly, 1959; Oghenemavwe *et al*., 2010). Several angles have been used to evaluate facial aesthetics. Facial angles such as nasofrontal, nasofacial, nasomental, and mentocervical angles, were initially introduced to give insight into an ideal facial profile (Powell and Humphreys, 1984). Other angles such as H-angle and Z angle were reported (Merrifield, 1966; Holdaway, 1983). The angle of convexity which is formed by soft tissue glabella,

subnasale, and soft tissue pogonion was also documented in the literature (Legan and Burstone, 1980). Since the early 50s, the photometric approach for facial analysis was introduced (Stoner 1955), and the analysis was based on the lateral and frontal photographic records taken in the natural head position (Arnett and Bergman, 1993a, b).

The facial angle can be classified into three; class I (165–175 degrees), class II (<165 degrees), and class III profiles (>175 degrees), based on the angle of the facial convexity (G–Sn–Pg) (Fernández-Riveiro *et al*., 2003). The extensive aesthetic analyses of the facial profile focused on anasolabial angle, mentolabial angle, and the total facial contour. Lines *et al*. (1978) incorporated the nasal angle formed by the tangent to the nasal dorsum and the facial plane. It was later noted that the most frequently used facial angles were thenasolabial angle and the angle of the contour of the maxillary and mandibular sulcus was frequently used (Anic-Miloševic *et al.,* 2008).

The human sculptures produced in ancient Greece were derived from proportions that followed established rules or ‘canons’ (Edler, 2001). These rules were incorporated to the ‘‘neoclassical canons’’ for the human face by Renaissance artists (Farkas *et al.,* 1985; Le *et al.,* 2002). These canons were based on the assumption that certain fixed ratios existed between different parameters of a harmonious face. Subsequently, these canons were adopted by medical artists, anatomists, and aesthetic surgeons and continue to be used to this day. Farkas was the first investigator to test the applicability of neoclassical facial canons, studying samples of 6, 12, and 18-year old North American Caucasians (Farkas *et*

al., 1985). These canons describe the aesthetic proportional relationships of the face. These form the foundation upon which modern facial analysis is based (Porter and Olson, 2001). The basic premise is that portions of an attractive face should follow certain defined ratios which summarise these principles in nine neoclassical canons. Four of the canons (I through IV) deal with vertical measurements, four canons (V through VIII) with horizontal measurements, and one canon (IX) with angles of inclination (Matory and Jr, 1986; Porter and Olson, 2001).

For the establishment of arelationship between anthropologicalvariables, fingerprint and face had the potential in this context. Ridge breadth correlates with hand length, hand and distal phalanx breadth (Cummins *et al.*, 1941). Loesch and Lafranchi (1990) showed that the a–b ridge breadth is related to wrist width, chest circumference and body mass index (slightly), but negatively with the length of lower limbs. The relationship of epidermal ridges with certain body dimensions (weight, height, and hand size and width), gripping and tactile sensitivity was also established (Ohler and Cummins, 1942; Cummins and Midlo, 1943; Loesch and Martin, 1984; Moore, 1989; Miller, 2009). Studies were also able to estimate stature from various body parts like hands, trunk, intact vertebral column, upper and lower limbs, individual long and short bones, foot and footprints (Pelin *et al*., 2005; Bidmos, 2006; Duyar *et al*., 2006; Krishan, 2008a). Moreover, other parts of the body like head and face variables have been used to estimated stature (Krishan, 2008b).

Although generating a biometric feature from another is a challenging research topic, generating face characteristics from only fingerprints is especially interesting and attractive idea for applications (Ozkaya and Sagiroglu, 2008a). It was found that there was extensive literature on fingerprint identification and face recognition (Maio *et al.*, 2003; Jain *et al.*, 1999). Some of the scientists focused on analyzing the similarities in fingerprint minutiae patterns and facial variable in identical twin (Jain *et al.*, 2002). Consequently, this similarity supports the idea that there might be some relationships among fingerprints and faces. The relationships among biometric features of the faces and fingerprints were experimentally shown covering the generation of face borders, contours, including ears, models, including eyebrows, eyes and mouth and parts of the face; inner face with eyebrows and face borders with ears (Ozkaya and Sagiroglu, 2010).

1.2 STATEMENT OF THE RESEARCH PROBLEMS

Dermatoglyphics in developing countries such as Nigeria has focused on dermatoglyphic patterns and ridge count (Ogunranti and Sorgia 1984; Danborno and Idris, 2007; Jaja, and Igbigbi, 2008; Ekanem *et al.*, 2009; Oladipo *et al.*, 2009), but not so much on other features such as ridge breadth, pores and minutiae which is useful in personal identification or forensic science. Hence, our current knowledge of variability of the relevant features is inadequate. Sexual dimorphism in thumbprint and facial profiles were intensively studied among the different populations, Nigerians inclusive. However, the concept of fluctuating asymmetry in both profiles needed to be investigated especially among Hausas, where such is absent or scanty.

As facial cosmetic surgery is becoming more common among people from various ethnic backgrounds, the concept of a single aesthetic standard of beauty is inadequate. Several studies have evaluated facial anthropometric differences between racial groups with emphasis on neoclassical facial canon and its variation. Such attempt is, however, scanty or absent among Hausa ethnic groups.

Determination of therelationship between various anthropological variables is one of the important practices in the field of biological anthropology. However, the correlations between thumbprint and facial profiles together with other body variables; height, weight and BMI have received less attention among Hausa. Even among other populations, the anthropological approach to establishing the relationship is often neglected.

1.3 JUSTIFICATION OF THE STUDY

There is aneed for base-line anthropological data among the Hausa population especially with respect to thumbprints and facial profiles. Extraction of various forms of variable associated fingerprint and facial trait profiles will enrich the information regarding the two profiles, hence serve as database and reference information as the need may arise. Establishment of therelationship of linear facial dimensions and angles with other thumbprint profiles such as ridge thickness, density, minutiae and pore received less attention in the literature. There is very little or no such attempt among Hausa population.

1.4 RESEARCH HYPOTHESES

i. There will be sexual dimorphism and sexual discrimination features in thumbprint profiles (pattern, minutiae type, ridge density and thickness, ridge pores), and facial profiles(linear dimensions and facial angles) among Hausa population of Kano.

ii. There will be theexistence of fluctuating asymmetry in thumbprints and facial profiles in male and female Hausa population of Kano.

iii. There are present of neoclassical facial proportions canon in male and female Hausa population of Kano.

iv. There is anassociation between the thumbprint patterns and facial proportion among Hausa population of Kano.

v. There is acorrelation between the thumbprint ridge density, minutiae, thickness, pores, linear facial dimensions and angles, height, weight and body mass index in male and female Hausas.

vi. Body mass index will be predicted from thumbprints and facial profiles among Hausa population of Kano

1.5 AIM AND OBJECTIVES OF THE STUDY

1.5.1 Aim of the Study

The overall aim of the study was to establish a relationship of thumbprint profiles, facial profiles and body mass index (BMI) of the Hausa of Kano State, Nigeria.

1.5.2 Objectives of the Study

The objectives of the study were to investigate among Hausa population of Kano State, Nigeria, the:

i. Sex discrimination in thumbprint ridge pattern, density, minutiae and pores.

ii. Sex discrimination in linear facial dimensions and angles.

iii. Sexual dimorphism in asymmetry indices in thumbprints and facial profiles.

iv. Neoclassical facial proportion canon in male and female.

v. Association between neoclassical facial proportion and thumbprint patterns.

vi. Relationship between facial dimensions with thumbprint ridge count and minutiae.

vii. Relationship between linear facial angles with thumbprint ridge count and minutiae.

viii. Relationship between BMI with facial and thumbprint profiles .

ix. Prediction of BMI from facial and thumbprint profiles.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 EMBRYOLOGY OF FINGERPRINT AND FACE

2.1.1 Development of Fingerprint

The crucial events for the establishment of the epidermal ridge pattern take place from the 10^{th} to 16^{th} weeks of development. At the10^{th} week, embryonal volar skin consists of the layered epidermis on top of the more amorphous fibrous dermis. The epidermis consists of three layers: periderm, the intermediate layer and the basal layer (Babler, 1991).

During 11^{th} week basal layer of epidermis consists of columnar cells, whose axis is perpendicular to theskin surface. The basal layer becomes undulated, which becomes prominent and forms a fold of the epidermis into thedermis. These folds are called primary ridges. These established the future surface patterns, which becomes well pronounced at the 16^{th} week. Fingerprints patterns are encoded at the interface between dermis, therefore the pattern cannot be destroyed by superficial skin injuries (Babler, 1991; Kucken and Newell, 2004). Primary ridge formation does not occur simultaneously on the volar skin. The formation usually starts at a certain area in the middle of the volar pad (ridge anlage) and along nail furrow, little later along the interphalangeal flexion creases. The area of the ridge anlage usually coincides with the center of the whorl and loops if such pattern shows up. In this way, there are three ridge system on the fingertips (starting from the ridge anlage, the nail furrow, and the flexion creases), which slowly spread over the fingertip. At the location where these ridge systems finally meet, triradii (delta) arises (Kucken and Newell, 2004).

Another feature found in association with fingerprint are pores. They are defined as the openings of subcutaneous sweat glands that are presented on the superficial layer of the skin, the epidermis. Moreover, pores also penetrate into the dermis starting from the epidermis (Jain *et al*., 2007). During the fifth month of intrauterinelife, the first sweat gland formations begin; however, the epidermal ridges are not constructed until the sixth month (Hirsch and Schweichel, 1973). This indicates the stability of pore on the ridges before the process of epidermis and dermis formation is completed and are unchanged once the ridge formation is completed (Jain *et al*., 2007). Each ridge unit contains one sweat gland, and pores are often considered evenly distributed along ridges and the spatial distance between pores (approximately 0.48 mm) frequently appears to be in proportion to the breadth of the ridge (Ashbaugh, 1999). The presentation of thepore on the ridges can either be open (when entirely enclosed by a ridge) or closed (when intersects with the valley lying between two ridges) in a fingerprint image, and this depends on its perspiration activity. It has been reported that two separate prints of the same fingerprintpore may not be exactly the same, as a pore may be open in one and closed in the other print (Jain *et al*., 2007).

Incipient ridges, which occur in about 45 percent of the people and 13.5 percent of the fingers, may appear between normal friction ridges some time. This is normal forming ridges that remained “immature” at the time of differentiation when primary ridge formation ended. They also contain pores like other ridges, this may be as a result of theformation of pores during the early growth of the ridges (Ashbaugh, 1992; Jain *et al*., 2007).

2.1.2 Hypotheses on Ridge Formation

Although no accepted mechanism for ridge formation exists to date, the following hypotheses prove to be very important in the understanding of fingerprints formation

2.1.2.1 Folding Hypothesis and Other Mechanical Hypotheses

In 1883, it was speculated that the ridge pattern is established as a result of thefolding process, which is induced by differential growth. In 1926, it was stated that the ridges form as a result of afolding process which parallels to the largest growth stress. 1n 1927 and 1932, the folding process idea was promoted with a lot of histological evidence (Bonnevie, 1927; Bonnevie, 1932). It was argued that there is intense cell proliferation in the basal layer of the epidermis resulting in cylindrical cells, which evades the stress by folding toward the dermis, thus resulting in the formation of primary ridges. Unfortunately, until now no attempt has been made to identify the sources of stress that produce the observed patterns of fingerprints (Kucken and Newell, 2005).

2.1.2.2 Nerve hypothesis

In 1986 and 1989, Dell, Munger and Moore linked the fingerprints pattern to the nervous system. They Stated that the fingertips are innervated before ridge formation start by thehexagonal pattern of axons whose wavelength roughly equals to one of thefingerprints (Dell and Munger, 1986; Moore and Munger, 1989). Arguments against the ideas are the fact that a hexagonal platform cannot establish a ridge direction and ridge formation when innervations were prevented (Morohunfola *et al.,* 1992).

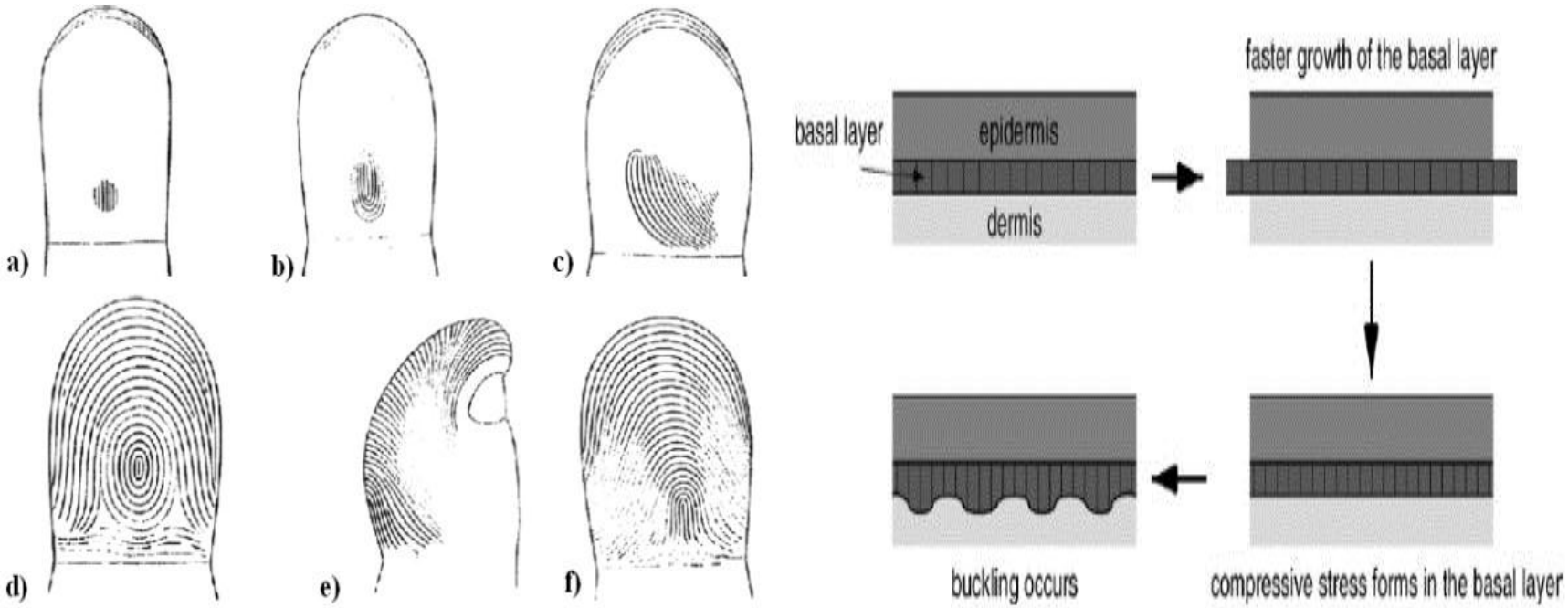


Figure 2. 1: Stages in spread and formation of epidermal ridges (Kucken and Newell, 2005).

2.1.2.3 Fibroblast hypothesis

In 1993, it was observed that topological properties of fingerprints pattern and cultivated fibroblast cell pattern are similar. Due to this similarity, they suggested that fingerprints are induced by pre-pattern of the fibroblast in the dermis. On the basis of interactions between extracellular matrix, haptotaxis and other processes, a model was developed (Bentil and Murray, 1993).

2.1.2.4 Microcirculation hypothesis

It was hypothesised that the complexity and characteristics of fingerprints can be deducted from a microvascular point of view. It was suggested that the regular disposition of capillaries on the palmar side of a finger sharply followed the cutaneous sulci of the fingerprint (Jain *et al*., 2007). A very specialised tubular-shaped structure capillaries are formed around the sweat glands and the concentration of these structures is higher on the dorsal side of the finger compare the palmar side (Sangiorgi *et al*., 2004). These findings among others provide further scientific evidence of the uniqueness of fingerprints (Jain *et al*., 2007).

2.1.2.4 Biochemical hypothesis

It was stated that the existence of reactive system on the skin surface gives an explanation for the pattern found. The high stability of the emergence of the pattern can be explained that is the repetition of the pattern was due to a specialized biochemical system allowing the formation of the wrinkles in the fingerprints. The biochemical factors involved are

called morphogens. Although mechanical growth factors also play roles in the process, the exact influence of each factor on the formation of surface pattern becomes an experimental challenge that will reveal the morphogenesis of fingerprints (Diego and Angelica, 2011).

2.1.3 Factors Influencing Fingerprints Pattern

Various factors suggested by numerous scientists to be the major driving forces in the pattern and formation of fingerprints, include:

2.1.3.1 Boundary effects

The boundaries on the fingertips include; nail furrow, flexion creases, and margin of the fingertips. It was observed that primary ridges lines are parallel to the nail furrow and major flexion creases as well as perpendicular to the outline of the fingertip. This implies that furrows and creases act as obstacles to expansion and greatest stress perpendicular to these obstacles (Kunken and Newell, 2005).

2.1.3.2 *Volar pads*

The Volar pads are temporary eminence of the skin surface that forms during the 7^{th} week of development and start to digress at about the 10^{th} week, corresponding to thecrucial period of fingerprints developments. The pads are found at the fingertips, in the interdigital areas and sometimes in the hypothenar and thenar regions as well. From the studies of the human embryos, monkeys, and malformed hands, it is constantly being observed that

highly rounds symmetrical pads (that is large curved pad) at the fingertips exhibit whorls; less well developed asymmetric pad show loops, where thedirection of the loop opening is determined by the asymmetry of the pad. Pad slanted to the right gives rise to loop opening to the left and vice versa; small indistinct pad (flat pad) gives rise to arches (Cummins, 1929).

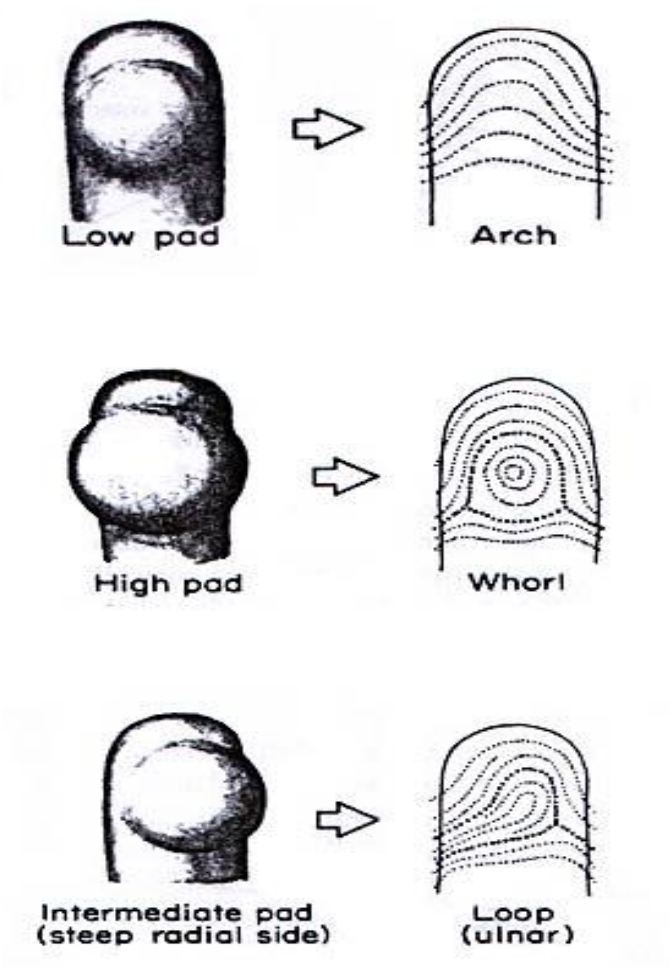


Figure 2. 2: Different nature of volar pads (Kucken and Newell, 2005).

2.1.3.3 Genetic factor

There is a rare genetic mutation that causes only a handful of people around the world to be born without fingerprints. Geneticists have identified the gene believed to cause this strange disorder. All of the people with the disorder had a mutation of the gene called *SMARCAD1*gene. The SMARCAD 1(SWI/SNF-related matrix associated actin dependent regulator of chromatin subfamily A containing DEAD/H box 1) is a protein that are encoded by the SMARCAD gene, which contains 1026 amino acids; 117.402 kDa.Proper expression of SMARCAD1 may be important to fingerprint development, and disruption of its expression is believed to cause adermatoglyphia, the absence of fingerprints (Adra, 2001).

2.1.3.4 Merkel cells

The Merkel cells are cells in the epidermis, which are in contact with nerve endings. Their origin and function are still controversial. The cells form in the hexagonal pattern and are found later at the base of the epidermal ridges. The location of the Merkel cells determines the minutiae of fingerprints (Kunken and Newell, 2005).

2.1.4 Development of the Face

The understanding of the development of the facial region gives insight into themechanism of normal facial variation and congenital deformities when normal facial development goes awry (Som and Naidich, 2013). Various parts are involved in the process of development of

the face. They include head ectoderm, which contributesto the formation of the face and oral cavity; and the neural crest mesenchyme, which contributes to the first branchial arch and its derivatives (Osumi-Yamashita, 1996).

Through series of highly coordinated and preprogrammed events, the human face starts to develop during the 4th week of embryonic development. By the 6th week, the external face is completed. Between the 6th and 8th weeks, the development of the palate subdivides nasal and oral cavities. This development continues into the 12th week with thecompletion of the soft palate (Larsen, 1993). The development of face can be a complex phenomenon however, the main event that led to the manifestation of the facial trait can be summarised as follows:

2.1.4.1 *Late third to fourth week*

Immediately after theclosure of anterior neuropore, the forebrain enlarges and pushes the overlying ectoderm forward and laterally, resulting in the fronto-nasal process. An ectodermal covered invagination, the stomodeum also form beneath the frontonasal process. The stomodeum comes to abut the endoderm of the developing foregut to form the oropharyngeal membrane. By the end of the fourth week, the nasal placodes (or olfactory placodes) develop as well-defined epiblastic thickenings of two to three cell layers on either side of the frontonasal process (Warbrick, 1960; Kim*et al*., 2004; Som and Naidich, 2013).

2.1.4.2 Fifth week

In the early fifth week, each nasal placode starts to sink below the surface as a nasal groove, first the lateral nasal process develops followed by the medial nasal process (later with an enlarged caudal end that is called the "globular process of His") (Bossy, 1980; Kim*et al*., 2004). The two nasal processes form a downward-facing "horse-shoe" with the open end facing the stomodeum. In the same week, communication between the fore-gut and the outside is established as a result of thedisintegration of theoropharyngeal membrane.

Mesenchymal growth in the first branchial arch produces medially growing processes, first the maxillary process and then the faster growing mandibular process on each side, which rapidly extends to the facial midline and merge. The stomodeum (the future mouth) is now surrounded by the frontonasal process above, the paired maxillary processes on either side and the paired mandibular processes below, the future lower jaw (Warbrick, 1960; Kim *et al*., 2004). By the late fifth week, nasal pits formed from deepening nasal grooves continue to actively deepen and thrust back into the stomodeum, forming the nasal sacs. The grow maxillary processes results in medial displacement of the nasal sacs. The Bucco-nasal groove appears as a groove between the maxillary process and the medial nasal process, fusion across this groove occurs in the fifth week to forms the lower nostril region. At the same time, there is also some ventrolateral expansion of each medial nasal process, which causes compression of each nasal sac aperture into a slit-shaped opening (Bossy, 1980; Kim *et al*., 2004).

2.1.4.3 *Sixth week*

In this week, the medial aspects of the two medial nasal processes form a thickened mesodermal region anteriorly beneath and between the early nasal sacs. This constitutes intermaxillary segment, and it may actually be formed by the joining of the globular processes of His (Warbrick, 1960; Kim*et al*., 2004). By the mid of sixth week, the oronasal membrane ruptures to form the primitive posterior choana. With the dissolution of the oronasal membrane, the primitive nasal cavity and posterior primitive oral cavity once again communicate freely. Later, they become separated by the formation of the palate. The future nostril formation is completed anteriorly, and this is separated from the developing oral cavity (Kim *et al*., 2004).

By the end of the sixth week, the lateral nasal processes begin to unite with the maxillary processes to form the lateral nose and the lateral border of the nostril on both sides. On each side of the face, along the junction between the maxillary and lateral nasal processes nasolacrimal groove is formed. This later close to establish continuity between the side of the nose formed by the lateral nasal process and the cheek formed by the maxillary process. Other facial features that formed in this week include; lateral palatine processes, nasooptic furrow, external ear, labiogingival laminae, dental lamina as well as eyelids. (Warbrick, 1960; Kim*et al*., 2004; Som and Naidich, 2013).

2.1.4.4 *Seventh week*

During this week, each nasal cavity opens to the outside through a nostril and communicates posteriorly with the pharynx through the primitive choana (Warbrick, 1960; Kim*et al*., 2004). By the mid-seventh week, theproliferation of epithelial cells that form an epithelial plug filled the anterior lumen of each primitive nasal cavity. The medial nasal processes and the maxillary processes fused to form most of the upper lip and upper jaw on both sides. The two merged medial nasal processes then form the philtrum and columella and complete the formation of the upper lip. The fronto-nasal process gets displaced superiorly and posteriorly. Hence, the fronto-nasal process does not contribute to the definitive upper lip, jaw, or nasal tip formation. It is also noteworthy that the medial migration of the maxillary processes forms not only the lateral upper lip but the upper cheek regions, resulting in continuity of the upper jaw and lip (Kim*et al*., 2004). In the same week, external ear fully developed, the palatal shelves elevate and fuse, forming secondary palate, future nostril now complete, eyes move more to mid-line and fusion of maxillary and mandibular processes narrow the width of the mouth and complete lower cheeks (Som and Naidich, 2013).

2.1.4.5 *Eighth to twelfth week*

In this week, lateral nasal wall is well-developed; facial muscle primordial appear and muscles developed by the 9^{th} week. By 9 to 10^{th} week; The fusing of the nasal septum with palate is complete by the 12^{th} week. The embryonic woven bone of the maxilla can be seen between 9 and 10 weeks, and it then enlarges relative to the nasal cavity. By twelfth week, ossification centers of all facial bones are present. Beyond the 12^{th} week, the epithelial plug

in the nasal cavity dissolves, and by the mid-16th week, the nasal passages are complete and open. The region occupied by the plug become the nasal vestibule, which is a ridge separating the nasal cavity proper from the vestibule of the nose (Nishimura, 1993).

2.1.5 Factors Influencing the Facial Trait

Aging is one of the constant factors that affects any biological entities including facial trait. It was noted that the most apparent changes in the face are secondary to ageing processes. Soft-tissue and bone structures are the two important components affected resulting in the changes in the facial characteristics and overall shape of the human face, mainly in the dento-alveolar region (Albert *et al*., 2011; Sveikata *et al*., 2011). Two factors intrinsic and extrinsic, are considered in this context. Intrinsic ageing is caused by internal biological factors, whereas extrinsic ageing is caused by environmental influences (Albert *et al*., 2011).

2.1.5.1 Intrinsic face ageing factors

Intrinsic factors causing facial ageing are mainly due to the natural alteration that occurs in the facial trait. For example, in the soft tissues lose their elasticity, muscle tone, and volume are some of the changes (Coleman and Grover, 2006; Isse, 2008), whereas for bony shape modifications this results from the life-long and on-going process of bone remodeling (Sadick *et al*., 2009; Zimbler *et al*., 2001). Affecting these complex facial changes are an individual's biological sex, ethnicity, and features purely unique to the individual, such as hyperdynamic facial expressions (idiosyncratic) (Albert *et al*., 2011). Some of these intrinsic factors are;

2.1.5.1.1 Soft tissue age changes

For better understanding and conveniences, amethod for evaluation of anatomical changes due to soft tissue aging process divides the face into the three; upper, middle and lower third (Coleman and Grover, 2006). In addition, ear is considered in isolation (Albert *et al*., 2011).

In the upper third of the face (forehead and brows), there is anotable reduction in skin elasticity, and the influence of gravity and repetitive periorbital muscle contractions, leading to droop of brows. Upper eyelid skin elasticity fades, this results in an excess of unsupported skin which manifeste in theform of folds in the eyelids which leads to tired or "old" facial appearance (Sadick *et al*., 2009). In the mid-facial region (mid face and nose) with anincrease of age fat deposition in the cheeks begins to fade. The weakening of associated ligaments holding the malar fat pad in position occurs and a naso-labial fold develops (Sadick *et al*., 2009). Between 20's to 30's naso-labial lines begin to develop, by 40's to 50's the folds increase in depth and this continues to deepen upto 60's and beyond (Albert *et al*., 2007). It was also reported that the nose moves forward and downward with advancing age (Bishara *et al*., 1998; West and McNamara, 1999).

In the lower face (lips, chin, lower cheeks, jaw line, and neck) there is formation of vertical rhytides above the vermilion border as a result of skin thinning with increase of age (Sadick *et al*., 2009) and an ornamental groove, or lines forming at the angles of the mouth, develop usually in the 40's and deepen with advancement of age (Albert *et al*., 2007). A Bucco mandibular crease may arise as a crease at the side of the cheek above the lower jaw and

with avertical orientation. Jowls (fat deposition below the jawline), along with a sagging chin, use to occur in the 50's and become more pronounced in the 60's and beyond. A longitudinal study of cranio-facial age changes found that upper lip length increases by average of 3.2 mm for individuals first measured in their late teens then re-measured again in their 40's. Moreover, in 40's and late 50's the increase is of about 1.4 mm.It was further noted that consistent with upper lip length increases, significant upper lip thinning occurred. An average of 3.6 mm thinning from the late teens to 40's and about 1.4 mm thinning from the 40's to late 50's was reported (Iblher *et al*., 2008; Pecora *et al*. 2008). However, the extent to which facial feature changes affect an individual's facial appearance is unknown (Albert *et al*., 2011). The changes result in the lower third of the face appear smaller relative to the upper and middle thirds, stray from the ideal, approximately equal proportions. Ageing changes from the middle third of the face may contribute to this appearance, as nasal tip ptosis may create the appearance of a shortened upper lip (Shaw *et al*., 2010).

It was also reported that ear width, length, relevant ratios, ear areas and angles relative to the midline of the face, and asymmetry in individuals aged 4 to 73 years had significant age effect with respect to linear distances, areas, and symmetry which increased as age advances (Sforza *et al*. 2009).

2.1.5.1.2 Bone remodeling and associated changes

Formation, removal, and replacement of bone is considered as a natural process occurring throughout life, through aprocess called bone remodeling. Bone remodeling is linked to the

functional need of an individual's body where there is a need for bone tissue, it is deposited; where it is not needed, it is resorbed. Depending on the loads and stresses placed on the skeletal system, nutrition, and other factors affecting the individual, the density, and thickness of bone will vary (Briggs, 1998). The facial bones retain the capacity for remodeling at any age of life (Belfor, 2009).

During youthful age, particularly before the age of twenty and with peak velocity at puberty, the deposition, growth, and modeling of bony tissues predominate. This sequential, chronological process is physically evident in the changing shape, height, and facial structure of different gender with entry into early adulthood (Taister *et al*., 2000). The facial skeleton appears to rotate in a way that the frontal and maxilla bone move anteroinferior and posterosuperior respectively. This rotation causes bony angles to become acute and this may have an effect on the position of overlying soft tissues. These changes appear to be more dramatic among female groups (Richard *et al*., 2009). By age 28, the formation and growth of the human skeletal system in most individuals is complete and physical changes occurring after this developmental milestone primarily involve bone remodeling, resorption and tissue degeneration (Briggs, 1998; Neave, 1998). Cranio-facial skeletal changes related to the adult ageing process, or more specifically, bone remodeling, result in alteration in the morphology of the face. This alteration (ranging from 1.1 mm to 1.60 mm) in cranio-facial dimensions have been found along body planes, notably; the horizontal, vertical, and sagittal planes, and in the dento-alveolar region of the face (Albert *et al*., 2011).

In the horizontal plane, the changes that occur include increases in overall head circumference, the length of the head (anterior to posterior), bizygomatic breadth (cheek bone to cheek bone), and the width of the head (Behrents, 1985). Horizontal size increases have been found to occur all throughout adult life, from the 20's to the 80's (Israel, 1977). For theverticalplane, anterior face height increases are one of the typical scenarios. It was suggested that anterior face height tends to increase more in the lower part of the face than the upper face (Forsberg *et al*., 1991; Bondevi, 1995; West and McNamara, 1999). In the sagittal plane, theslight anterior-posterior cranial thickness increases significantly (Doual *et al*., 1997), although its direct contribution, if any, to soft tissue facial ageing has yet to be reported and or studied (Albert *et al*., 2011).

In the dento-alveolar region, the facial morphological alteration such as continued eruptive movement of the teeth likely tied to maxillary backward displacement, or retrusion was evident between middle 20's to middle 40's (Forsberg *et al*., 1991; Akgul and Toygar, 2002). Other variables like mandibular length has also been shown to slightly increase, from the early 20's to early 30's (Bondevi, 1995). It was also reported that mandibular length increases from young age category (mean age 17 years) to middle age category (mean age 47 years). The increase was linked to nature of the bone growth among the young age category may not be completed (Pecora *et al*. 2008).

According to Shaw *et al*. (2010), dimensions (length) of the mandible across three adult age groups; young (20-40 years), middle (41-64 years) and old (65 years and older) were significantly decreased across the groups. For example, in males the mean mandibular

length for the young age group (20-40-year-olds) decreased from 90.4 mm to 83.1 mm in the middle age group (41-64 years), yet by old age (65 years and older), the mean mandibular length was 83.0 mm. In females, there was a similar pattern of decrease. It was concluded that major age changes seem to occur in the 40's and 50's (Albert *et al.*, 2011). Another mandibular parameter such as mandibular ramus height and body height also decrease. However, the mandibular angles increase as adult age progresses (Shaw *et al*., 2010). Although changes in the bony face have been quantified, the degree to which the dimensional shifts discussed above affect the overall appearance of the aging face is not well understood.

2.1.5.1.3 Gender

The facial aging process of male and female may have so many features in common, attention to the particular differences in the aging male is warranted (Leong, 2008). The sexual dimorphic features in the male face include the presence of facial hair, increased facial vascularity, increased thickness, increased sebaceous content, hormonal influences, and potentially differing rates of fat and bone absorption during the life cycle. Females tend to develop more and deeper wrinkles in the perioral region and, their skin contains a significantly smaller number of appendages compare to male (Paes *et al*., 2009).

2.1.5.1.4 Body Composition

Body composition such as muscle mass, fat content among other is known to change as people age in adulthood. Some of the changes can be presented in the form of muscle fibers atrophy, which may lead to fat accumulation, thinner of the appendages, expansion of abdominal girth, due to a general weakening of abdominal muscles (Overfield, 1995). The ways and manner in which muscle loss and weight gain affect the aging face are not yet to be understood as there is a paucity of published literature specifically addressing weight gain and loss in and around the face. Generally, fat stored in the face shifts position with anincrease in ages. For example, fat from the upper cheeks diminishes and the face may take on a more hollow appearance. Also fat that drops toward the jawline create the appearance of jowls (Albert *et al*., 2011).

2.1.5.2 Extrinsic face ageing factors

Extrinsic factors influencing facial ageing may be caused by external influences such as environmental (exposure to solar ultraviolet rays, lifestyle such as diet, drug use, and or smoking) (O'Hare *et al*., 1999; Taister *et al*., 2000), orthodontic treatment, teeth loss among others (Sveikata *et al*., 2011)

2.1.5.2.1 Environmental factor

Premature ageing of the skin of the face (which is more delicate) may be due to prolong or frequent exposure to environmental agents, such as sunlight (ultraviolet radiation) and the wind or arid climates (Uiotto, 1997).

The ultraviolet radiation accelerates the ageing processes by dryingand destroying the cells and underlying structure of the skin. This also gives the skin a furrowed, thickened appearance and hastens the development of wrinkles, especially around the eyes as a product of squinting (Shaw *et al*., 2010). This result in a phenomenon known as photoageing (Victor, 2003). The changes in photoageing include wrinkling, elastosis, actinic keratoses, irregular pigmentation (Situm *et al*., 2010).

Other environmental factors like aridity and wind also dehydrate the skin, contributing to the formation of wrinkles; however, the effect of ultraviolet radiation from the sun on the facial tissues is by far greater compared to these agents. With continued exposure to the ultra-violet rays and other elements, the color and texture of the face can change, result in blotchy, yellowish, and leathery, with loose, inelastic, hyperpigmented skin. The superficial blood vessels of the skin may become prominent as networks called spider veins, adding to the skin's overall mottled and blotched condition of the skin (Neave, 1998).

With respect to lifestyle, the potential detrimental effects of tobacco smoking have been widely reported in the literature. In older individuals, smoking has been found to be an important determinant of macroscopic skin ageing and wrinkling (Lopez-Hernandez *et al*., 1995; Fedok, 1996; Leung and Harvey, 2002). In line with this, it was noted that skin ageing does not clearly provides an objective measure of cumulative ultraviolet exposure (Sveikata *et al*., 2011). Although the role of smoking in the skin wrinkling was reported to be minor (O'Hare *et al*., 1999).

2.1.5.2.2 Orthodontic treatment

The position of the teeth may have aninfluence on the facial appearance. Any alteration in the position may result in the change in the position of the teeth as the case may be in orthodontic treatment. Though children and teenagers are the most affected population in this regards, it is not uncommon for adults and may impart a greater change in facial appearance in these subjects, especially when the goal is to achieve aesthetic results (Sveikata *et al*., 2011). The upper lip length increased significantly by 4 mm in older subjects, whereas for lower lip elevation the situation is not the same. The significant effect of increasing lip coverage of the maxillary teeth indicates that age should be included in orthodontic treatment planning (Van der Geld *et al*., 2008). The dynamic measures show that the muscles' ability to create a smile decreases as age advances (Desai *et al*., 2009).

In the process of extraction of premolars and molars in the upper or lower jaws. The main differences in soft tissue between the patients after the treatment are more retruded lower lip and a more pronounced lower labial sulcus in those patients subjected to extraction (Bravo *et al*., 1997). In thecase of extraction of the wisdom teeth in the maxilla, the face appears narrower, while for premolars from the mandible and pulling the remaining lower teeth together by means of orthodontics can markedly change the facial profile and at the same time reduces the effect of an inherited dominant chin. Untreated dental or surgical problems may also cause changes in the facial characteristics of an individual (Taister *et al*., 2000).

2.1.5.2.3 Teeth loss

There are several conditions such as physical injury or disease that may result in teeth loss. In healthy elderly persons ageing process alone does not result in critical loss of periodontal attachment (Huttner *et al*, 2009; McKenna and Burke, 2010). The effects of ageing on periodontal tissues intensify teeth and bone loss in old individuals (Lorentz *et al*., 2010). When an individual loses teeth, there is adecrease in the demand for support in the bone surrounding the teeth. This causes resorption of bone in inactive areas, a process which is more pronounced in the upper jaw than in the lower jaw. Since there is less bony tissue in the upper jaw, the height of the face decreases and this makes the lower jaw to be more prominent. An evidence suggested that loss of teeth is highly correlated with adecrease in the facial height, especially when the maxilla and mandible are involved (Barlett *et al*., 1992).

It was also reported that teeth loss from the lateral areas of the jaw can lead to the narrowing of the face as well as a hollowing of the cheeks. Moreover, total loss of the teeth will affect the density and thickness of the jaw bones (Megson *et al*., 2010), with overall changes in the facial profile by reduced size of the jaw area and fore-shortened facial appearance. The wearing of the occlusal surfaces of the teeth over time causes a reduction in the vertical height of the face, and also can lead to flattening and remodeling of the temporo-mandibular joint (Taister *et al*., 2000). On contrary, the individual with intact dentitions was reported to have stable total face height ratio throughout adulthood (Nasjleti and Kowalski, 1975; Crothers and Sandham, 1993; Gaivoronskii *et al*., 2010), however, face height increase due to teeth eruption (Barlett *et al*., 1992).

2.2 FINGERPRINTS PROFILE

2.2.1 Techniques Used in Capturing Fingerprint Profiles

There are various techniques used to obtain the ridge-and-valley pattern of fingertip skin impression (Xia and O'Gorman, 2003). The methods can be classified into direct and indirect sensing. In the indirect methods, the fingerprint is acquired using ink which involves coating finger with black ink which is then pressed and rolled against a paper card; the card is then scanned, to produce the digital image. This procedure is called "ink-technique:" and the process is termed as rolled offline fingerprint sensing technique this is still being used in forensic applications and as a screening tool for applicants seeking for sensitive jobs. On the other hand, direct sensing of fingerprints uses electronic signals with optical "live-scan" sensors that is based on frustrated total internal reflection (FTIR) principle. This involves light reflection that differentiates between ridges that touch the plate which obsorb light and the fingerprint valleys that do not touch the glass plates reflect the light. This differential property of light reflection allows the ridges (which appear dark) to be discriminated from the valleys (Jain *et al*., 2007).

New fingerprint sensing technologies are constantly being explored and developed. For instance, multispectral fingerprint imaging (MSI) has been introduced. This scans the subsurface of the skin by using different wavelengths of light [e.g., 470 nm (blue), 574 nm (green), and 636 nm (red)]. The fundamental idea is that different features of skin cause different absorbing and scattering actions depending on the wavelength of light. Fingerprint images acquired using the MSI technology appear to be of significantly better quality compared to conventional optical sensors for dry and wet fingers (Nixon and Rowe, 2005).

Another new fingerprint sensing technology based on themulticamera system, known as "touchlessimaging, "which was initially introduced by TBS, Inc. (Parziale and Diaz-Santana, 2006). As the name implies, atouch less imaging avoids direct contact between the sensor and the skin and, thus, consistently preserves the fingerprint actual features without causing any skin deformation in the process of imageacquisition. One of theessential characteristics of a digital fingerprint image is its resolution, which indicates the number of dots or pixels per inch (PPI) (Jain *et al*., 2007; Hiew *et al*., 2010).

2.2.2 Fingerprint Patterns

The first step in the analyses of fingerprint is theidentification of the pattern. The widely accepted classification of fingerprint classifies the prints into; whorl, loop (ulna and radial) and arch. Based on this classification several authors reported variation in frequency/percentage of this basic fingerprint patterns in order to establish the gender and inter-ethnic variations. For instance, it was observed that Hausa males had 30.15% as whorls, 65.91% as loops and 3.95% arches. In females, 29.33% were having whorls, 61.27% were having loops and 9.29% were having arches. In both sexes, a loop exhibited the highest frequency and arches the lowest. The males had more abundant whorls and loops than females, while the females had more abundant arches than males (Danborno and Idris, 2007).

Another study of digital dermatoglyphics of two ethnic groups in Nigeria, Yoruba and Igbo showed that in Igbo male having fewer whorls and more arches than the females. Whereas among Yoruba arch frequency was found to be higher. Radial loop and whorl were more

frequent in males than in female but for ulnar loop, female recorded higher in Igbos. Among the Igbo, thereverse trend was noted between gender with respect ulnar loop, radial loop and whorl frequencies (Igbigbi *et al*., 1994). Generally, in Nigerian males, the most frequent fingerprint patterns were loops (54.8%), followed by whorls (39.9%) and arches (5.3%). Similar frequencies were observed in females as loops (52%), whorls (39.4%) and arches (8.6%). In both sexes, loops exhibit high percentages and arches the least (Adamu *et al*., 2013).

Analysis of the fingerprints of the Tibetans showed that whorls (60.24%) were more abundant than loops (38.98%) in males. However, the females exhibited a much frequency of whorl (48.6%) and a higher frequency of loop (40.13%). The frequency of ulnar loop (47.13%) and arches (2.2%) was higher in female than among males who showed them as 36.83% and 0.76%, respectively. The Tibetans possess a high pattern intensity index (is the average number of triradii summed over all digits of an individual's), the index value of 15.28 which falls essentially within the Mongoloid range. This reflects the abundant of whorls and reduced frequency of arches (Tiwari and Chattopadhyay, 1968).

Among Israelis, population dermatoglyphic of fingers showed that female has alower frequency of whorls and radial loops and ahigher number of arches and ulnar loops then the males (Schauman and Alter, 1976). It was also reported that the most frequent fingerprint pattern type was the ulnar loop, followed by whorl. Arches and radial loops were found to

be less frequently among Spanish population. However, no significant association between gender and the type of general pattern was found (Gutiérrez-Redomero *et al*., 2007).

The South American Indians have greater variation in frequency as regards to pattern type of fingerprints than any other American population (Eskimos, North American Indians and Central American Indians) (Garruto *et al*., 1979; Demarchi and Marcellino, 1998) . The finger pattern type frequencies found in the two Argentinian samples show that whorls were more frequent on thumbs and ring fingers, whilst ulnar loops were more frequent on the middle and little fingers. The index fingers of both hands presented a higher frequency of arches and radial loops, with similar frequencies for whorls and ulnar loops (Gutie´rrez-Redomero *et al*., 2012). This is within the distribution range described for South American populations, and as with all other Andean populations analyzed, the Puna–Quebrada population had a high frequency of radial loops (Garruto *et al*., 1979; Baca *et al*., 2001).

The Argentinian samples were characterized by presenting more whorls and fewer ulnar loops than other Spanish population samples. This is also evident among Spanish populations (Gutie´rrez-Redomero *et al*., 2012). In the Region of Andhra Pradesh (India), the general distribution of the fingerprint shows that loops were the most frequent pattern (56.3%), followed by whorls (39.5%) and arches (4.2%) was the least. Based on the finger, whorls were most common on thethumb, index and ring fingers in males whereas in females loops on all fingers except ring finger presented a higher frequency (Sangam *et al*., 2011). In almost all populations, the loops and arches tend to have higher and least

frequency, respectively. However, their distribution with respect to fingers they occur varied with thepopulation.

2.2.3 Fingerprint Minutiae

One of the pillars of dactyloscopy identification is the use of fingerprint minutiae which can be assessed quantitatively (numerical standard) or qualitatively. The minutiae study and analyses have long been considered as the scientific bases that determine the process of individualization in personal identification using fingerprints (Ashbaugh, 1999; Vanderkolk, 2001).The variability of the minutiae among thedifferent areas of the finger remains the motivating factor for the various study of its variability across the different population. Although direct comparison of the different population studies is not feasible, due to the different methods used, however, it was already pointed out that the density of the minutiae varies in accordance with their location on the fingerprint (Kingston, 1964; Sclove, 1979; Lin, 1981). This was confirmed in some studies which found that a greater density of minutiae in the nucleus and in the delta than in the periphery of the fingerprint impression (Champod and Margot, 1996).

For a better exploration of the minutiae variability and comparison of findings between populations, a method of dividing fingerprint impression into two areas was introduced. The method involved designing of a circle associated with a specific number of ridges rather than one of a standard size, which divides the fingerprint area into two; area within the circle, and the area outside the circle (Okajima, 1966; Gutie´rrez-Redomero *et al*.,

2007). The main advantage of this method is that it allows comparison of the number of minutiae between the principal fingerprint patterns, side of the finger, sexes and populations. It also removes the difference in the size of the finger and that of the dermal ridges (Penrose, 1967).

It is important to know that the minimum number of minutiae needed to establish the identity of an individual varied considerably in the forensic laboratories of different countries. This variability is due to the fact that the minimum number of minutiae needed to prove identity has not been rigorously established (Margot and German, 1995; Ashbaugh, 1999; Stoney, 2001; Cole, 2001; Pankanti *et al*., 2002; Champod *et al*., 2004). This may be due to lack of common methodology in fingerprint minutiae study.

In the few studies conducted, it was reported that the most frequent minutiae in the index finger of Spanish population were ridge endings, convergences, and bifurcations. Sex-wise analyses show that ridge ending, convergences, bifurcations, and enclosures were more frequent in female (Gutiérrez-Redomero *et al*., 2007). Moreover, across several population ridge ending recorded higher frequencies, followed by bifurcation (Santamarı´a, 1955; Kingston, 1964; Steffens, 1965; Gupta, 1968; Okajima, 1970; Sclove, 1979; Lin, 1981; Stoney and Thornton, 1987; Gutiérrez-Redomero *et al*., 2011) and the least were opposite bifurcation and crossbar (Gupta, 1968), return (Santamarı´a, 1955), enclosure (Lin, 1981.), break (Steffens, 1965), trifurcate bifurcation (Sclove, 1979), point or dot (Stoney and Thornton, 1987), fragment (Okajima, 1970), Angular line (Kingston, 1964), dock (Spanish)

(Gutiérrez-Redomero *et al*., 2007), return (Puna–Quebrada population), M-C (Ramal population) (Gutiérrez-Redomero *et al*., 2012). A complete absence of minutiae type was reported in other population, for instance, theabsence of bridge in Indians (Sarkar, 2004) and return among Spanish population (Gutiérrez-Redomero *et al*., 2007). These findings may project the importance of theless frequent type of minutiae as indices of population variability. However, the fact that different methods and classification in minutiae analyses may reduce the magnitude and application of these findings should not be ignored.

The association between the number of minutiae and the principal pattern type was also reported. The study had already observed that in Danish males, a greater number of minutiae are found in the whorls, followed by the loops and arches in the entire fingerprint (Dankmeijer, 1980). However in Japanese population, the minutiae of the index finger found a greater number of minutiae in the arches and loops (Okajima, 1970).

In another study among Spanish population a different distribution in the density of the minutiae was also found. There was a greater concentration of minutiae in the arches and loops in the central region and more similarity distribution in the whorls between the inside and outside a circle. It was reported that minutiae distribution within the three basic fingerprint pattern; arches, loops, and whorls differ significantly for each characteristic in the two regions under consideration. The great number of minutiae was found in the whorls followed by the loops and arches, both in the entire impression and outside the circle.

However, inside the circle, the distribution is in reverse order (Gutiérrez-Redomero *et al*., 2007).

Differences in means for males and females were not found for Japanese in the earlier study, although among the German subjects counts were higher for males. Further study on Japanese population (twins) shows thelevel of sexual dimorphism in mean minutiae counts (Okajima, 1967). The males presented a statistically significant greater number of minutiae in the three areas under evaluation than the females. The differences between the sexes were significant for ridge endings, bifurcations, breaks, and cross-bars, which were on average found less often in the females (Gutiérrez-Redomero *et al*., 2011).

As far as gender is concerned, the number of minutiae in relation to the general fingerprint pattern (arches, loops and whorls) was, significantly greater for the males than for the females in whole fingerprint and outside the circle, with the exception of the arches in the count of the whole fingerprint (Gutiérrez-Redomero *et al*., 2007; Gutiérrez-Redomero *et al*., 2011). The differences between the sexes with respect to pattern type could be due to few ridges outside the circle for female subjects, but not inside the circle, showing that the gender differences found, as much in the area outside the circle as inside it, are not only due to the size of the finger and the different number of dermal ridges that exist between males and females, and that the type of the general pattern is not the one responsible for the gender differences at the interior of the circle, but that there must be other factors which determine the significant differences between the sexes with respect to the total number of minutiae found (Gutiérrez-Redomero *et al*., 2007).

2.2.4 Fingerprint Ridge Density and Thickness

In the field of dermatoglyphics, attention has been given to variables such as pattern type, pattern intensity index, and ridge count (Mavalwala, 1977; Wertelecki and Plato, 1979; Loesch, 1983; Figueras, 1993; Demarchi and Seisdedos, 1996; Karmakar *et al*., 2007, 2008). However, other variables of considerable value in human identification and characterization, such as ridge density, epidermal ridge breadth among others and variations in the same characteristic between sexes and throughout ontogenetic development, receive less attention (Kralik and Novotny, 2003; Gutiérrez-Redomero *et al*., 2011).

Previously the ridge density was studied using themethod of ridge counts which involve locating core and deltas (triradii) then the fingerprint ridge count is recorded by counting the number of valid intersecting ridges between these two points (Green and Young, 2000). In the recent time, two areas (ulnar and radial sides) on the distal side of the finger and one area at the proximal side of the finger, which is not subject to laterality was used. This enables the inclusion of digital patterns without delta (triradii), such as arches, thus reducing the sampling error resulting from the inclusion of only loops and whorls in the count (Gutiérrez-Redomero *et al*., 2011). This also eliminates the possibility of giving the whorl a chance of being counted two times.

Ridge density (RD), the number of digital ridges per unit area, varies according to sex, age, and population origin (Gutiérrez-Redomero *et al*., 2011). Sex differences was reported in fingerprint ridge different in different population including Spanish Caucasians (Gutie´rrez-Redomero *et al*., 2008), Spanish populations (Martı´n and Portabales 1986; Arrieta *et al*., 1987; Arrieta *et al*., 1990), Sardinian population (Floris, 1975), Egyptian (Eshak *et al*., 2013), Chinese and Malaysian (Nayak *et al*., 2010), some Indian populations (Nayak *et al*., 2010), including south Indian population (Nithin *et al*., 2011), Indo- Mauritian population (Agnihotri *et al*., 2012), Central Indian (Marathi) population (Kapoor and Badiye, 2015), Sudanese population (Ahmed and Osman, 2016), and Argentinean population (Rivaldería *et al.,* 2016). Furthermore, in almost all the populations, females tend to have agreater number of ridges than males. Several types of research define the ridge density for their own population for both sexes based on with equal prior probabilities P(C) =P (C0) = 0.5.In central India population, the statistical analysis of likelihood ratio and odds ratio shows that RD ≤12 ridges/25 mm^2 and ≤ 13 ridges/25 mm^2 are more likely to be males and females, respectively. Posterior probability using Baye's theorem shows that a fingerprint with ridge density ≤ 10 ridges/ 25 mm^2 is of male origin and ≤ 16 ridges/25 mm^2 will be more indicative of females (Kapoor and Badiye, 2015). This result shows little variation from RD in Chinese and Malaysian population, which states that fingerprint mean ridge density of 12 ridges/25 mm^2 or less is found to be more likely to be of males and a mean ridge count of more the 13 ridges/25 mm^2 is more likely of female origin in Chinese subjects. Fingerprint mean ridge density of 11 ridges/25 mm^2 or less is found to be more likely to be of males and a mean ridge count of more the 13 ridges/25 mm^2 is more likely of female origin in Malaysian subjects (Nayak *et al*., 2010). Among Egyptian population, females had more

ridge count (right: females > 21.0 ≥ males, left: females > 21.2 ≥ males, and higher ridge density (right: female >1.35 ≥ male, left: female > 1.5 ≥male) (Eshak *et al*., 2013).

These clearly indicate population and gender specificity of the finger ridge density. For Spanish population, the report indicates that in the radial area a dermal ridge count of 16 or less is most likely to be of male origin, and a ridge count of 17 ridges/25 mm^2 or more is most likely to be of female origin. Likewise in the ulnar area, a count of 14 ridges/25 mm^2 or less is most likely to be of male origin, and that a ridge count of 17 ridges/25 mm2 or more is most likely to be of female origin. However, if the prior probabilities are in favor of male subject P(C) = 0.7 and P (C0) = 0.3, due to more involvement of male in crime than the female in the real world, the threshold increased (Gutie´rrez-Redomero *et al*., 2008).

It was evident that females tend to have finer epidermal ridges than the males counterpart (Moore, 1989). The males were also reported to have coarser ridges than the femalesbyapproximately 10% (Kralık and Novotny, 2003). In addition to this valid evidences, it was also noted that the difference between the finger ridge density in males and females in a given area may link to sexual dimorphism in body proportions in which on average males are larger than females, therefore the same numbers of ridges are accommodated amongst the females in a small surface area thus, a higher density is noted amongst females (Krishna *et al*., 2010; Kapoor and Badiye, 2015).

Ridge density (RD) decreased with age and, at all ages, RD was higher on the distal (radial and ulnar) area, followed by the proximal sides. Females were found to have higher RD

than males when older than 12 years, but not when younger in the Mataco-Mataguayo population. Variations in RD in the Amerindian population based on sex, age, and topology were confirmed, and it is postulated that these variations are due to developmental differences among individuals and populations (Gutiérrez-Redomero *et al*., 2011).

When Mataco-Mataguayo and Spanish populations are compared, RD distribution patterns were similar, but the most notable differences between the two populations were found in the proximal area. In the ulnar and proximal areas, in both sexes, the Mataco-Mataguayo population presented significantly higher RD than the Spanish population. In the radial area, only the thumb and the index finger of both hands have higher RD in the Mataco-Mataguayo population than in the Spanish population (Gutiérrez-Redomero *et al*., 2011).

It was suggested that the radial and ulnar sides of the fingers seem to respond to different developmental instructions, which would be enough motivation for the use of radial and ulnar counts as separate variables (Jantz and Owsley, 1977). Further studies of other populations with different biological backgrounds are necessary in order to determine if these differential topological RD distributions correspond to a universal tendency. This is to keep a view that the consistencies and differences reported between different population (example Spanish and Mataco-Mataguayo) represent the existence of population-variable genetic factors that influence the development of ridges (Gutiérrez-Redomero *et al*., 2011).

Using a different method for assessing ridge density, it was noted that the average dermal ridge breadth in the second interdigital area was significantly greater in African Black

populations than in European populations (Jantz and Parham, 1978). In general term, some of these inter-population differences reported may not be as a result of the biological and anthropometric characteristics of each population, or of the developmental differences among individuals and populations, but due to differences in methodology, hence, it is difficult to make conclusive Statement (Gutiérrez-Redomero *et al*., 2011).

The ridge density determination methods can be used to clearly make an estimation of the epidermal breath on the tip of thefinger. The ridge breadth was estimated as the quotient between the lengths of the diagonal on the square measuring 5mm×5mm (7.07mm). The ridge breadth in the radial area was 10% and 7% greater in males than in females in the Spanish and Mataco-Mataguayo populations, respectively; likewise, it was 6% and 4% for the ulnar area, and 0.7% and 0.3% for proximal areas (Gutiérrez-Redomero *et al*., 2011).

Analyses of epidermal ridge breadth of human fingerprints on ceramic artifacts showed that mean epidermal ridge breadth can be used as an indicator of age (from birth to maturity) and sex of the artifact maker in adulthood, with 9% greater in males than in females (Kralik and Novotny, 2003). This is in line with earlier work by Ohler and Cummins (1942) which found that the ridges of females were 10.2% finer than the ridges of males. More, therecently similar result was observed among Spanish population in the radial area (10%), but they are higher than those revealed in the sample of the Mataco-Mataguayo population (7%) (Gutiérrez-Redomero *et al*., 2011). However, this gender differences is age sensitive,

as age advances the sexual dimorphism is more pronounce and significant (Loesch and Czyzewska, 1972; Gutiérrez-Redomero *et al*., 2011).

Considering finger as adepending factor, it was reported that the thumbs had a greater ridge breadth than all the other digits. The descending order of ridge breadth was thumb > index >medium > little > ring (Gutiérrez-Redomero *et al*., 2011). These results also agree with the quantitative studies of epidermal ridge morphogenesis carried out on aborted fetuses, both spontaneous and elective (Babler, 1979). A significant interdigital difference in interridge distance (amount of dermis between adjacent primary ridges). There was a radial-to-ulnar difference in interridge distance, with the fifth digit having the least interridge distance and thumb having the greatest. No interdigital differences in primary ridge breadth and depth were observed in the prenatal stage. These findings show that differences in surface ridge breadth do not necessarily reflect differences in primary ridge width; rather, they reflect variation only in the distance or amount of dermis between primary ridges (Babler, 1979; Gutiérrez-Redomero *et al*., 2011).

The mean ridge count of the first digit is invariably the highest among all digits, followed by the fourth finger. The lowest values belong to fingers II–IV. In all fingers, the mean ridge count is greater in males than in females with very minimal differences in finger II. (Fayrouz *et al*., 2012). For pattern type influence, no association was observed between epidermal ridge thickness and main pattern type in the radial and ulnar areas, while in the lower area there was in theSpanish population. In this area, the ridges were significantly

finer in the whorls than in the ulnar loops. The arches and the radial loops could not be statistically measured due to their low frequency of occurrence (Gutie´rrez-Redomero *et al*., 2008).

2.2.5 Fingerprint Pores

Proscope is a field of dermatoglyphics which involve the study of fingerprint pores to establish identity. Comprehensive studies have been performed on sweat pores and inked-print impressions. In this type of research, the number and size of sweat pores, their relative position and distances on the fingerprint, palm and sole imprints were normally compared and evaluated. Application of pores and ridge shape characteristics in fingerprint matching processes has been documented and focused are usually on pores that used afragment of fingerprints (RO'Leary *et al*., 1986; Bindra *et al*., 2000; Kryszczuk *et al*., 2004; Khosravi *et al*., 2011).

Pores have been used historically to assist in the process of fingerprint matching. Although most matching methods have emphasized minutiae based comparisons and used pores as ancillary comparison features. The utility of pores information alone to match prints has been reported in the literature (Ashbaugh, 1983; Stosz and Alyea, 1994). The concept of using pores to match prints has been essentially dormant during the rise of automated fingerprint recognition systems. In the quest of establishing identity, 20 to, 40 pores should be sufficient for such purposes (Ashbaugh, 1999). It was concluded that the size, shape, position and a number of pores on the ridges are individualistic and useful in personal

identification (Nickell and Fischer, 1999; Ashbaugh, 1999). This is more applicable when the number of ridge characteristics is inadequate, such as seen in partial finger-printing, Hence, poroscopy is commonly used as an independent method of establishing identity (Bindra *et al*., 2000; Jain *et al*., 2007). The smaller the fingerprint fragments, the greater the benefits of using pores (Kryszczuk *et al*., 2004).

Microscopes have been identified as anad-hoc tool in the poroscopy, which helps in determining the shape, size, location and number per unit centimeter of the ridge (two actual). Moreover, in order to avoid random section (Nagesh *et al*., 2011) of the ridge for pores analyses, a study (Tafazoli *et al*., 2013) used acircle with known area to demarcate the area of interest during poroscopy. There should be room for standardization of methods as well as providing the basis for comparison between sexes, populations etc by independent researchers.

Extensive investigations have demonstrated the uniqueness of the pore patterns for personal identification. Similarly, it was noted that pore-to-pore distance differs from individual to another and this variation depends on the location in the finger (Babler, 1991; Bindra *et al*., 2000). A study conducted among Indian population indicated that the number of pores (left thumb only) per centimeter of friction ridge ranged from 5 to 16.3 (8.40 ± 2.01) and 5.3 to 16 (8.83 ± 2.09) in males and females respectively. As the age advances, no significant difference was noted in the number of pores in both the sexes (Nagesh *et al*., 2011). This indicates the potential of the number of the pores other than any of the parameter that may

be influenced by age. The number of closed type of pores is greater than that of the open types, however, with anincrease in age the closed type of pores decreases with an increase in open pores. A study among Iranian male population the average number of pores per unit cm of ridge length varied from 10 to 11. It was observed that the pores usually were located at equal distances from each other in a single row along the middle of the ridge (Tafazoli *et al*., 2013). Pores located in the middle of the ridge were of the closed type and clear (43%), which supported the study from other population (Bindra *et al*., 2000).

In Iranian population, medium-sized pores were the most frequently in all areas of the print (76.16%), followed by large-sized pores (16.15%) and the small sized pores were the least frequently observed 7.99% (Tafazoli *et al*., 2013). For the shape of the pores, no significant difference between the sexes. In both sexes, highest numbers of pores were circular and oval shaped, and the least was the rectangular and rhomboid-shaped pores among Indian population (Bindra *et al*., 2000; Nagesh *et al*., 2011), this can also be influenced by age (Tafazoli *et al*., 2013).

It was reported that 9 to 18 pores per centimeter of theridge were found in thefinger and palm prints of two accused persons in a theft case (Ashbaugh, 1999). Another study also indicated that in every centimeter of ridge 8 to 25 pores can be located, but this varied with theregion as the minimum number of pores was observed in the thenar and maximum in the hypothenar regions (Bindra *et al*., 2000). Moreover, the findings of the Nagesh *et al.* (2011) from the pulp of the finger shows that the number of pores per centimeter of the ridge is

less in distal parts of the finger compared to the palm. The majority of the ridge pores were of theclosed type, followed by open on one side and open on both sides in both sexes (Bindra *et al.*, 2000).

There are advantages attached to the use of pores in automatic fingerprint recognition systems. One of such is that pores are more difficult to be damaged or mimicked than other feature of the fingerprint such as minutiae. Secondly, the distribution of pore on the fingerprint is quite numerous. Even a small fragment of afingerprint can have some reasonable number of pores (Oddy and Stosz, 1997; Parthasaradhi *et al*., 2005). Moreover, using pores characteristic, a fake fingerprint image can be detected because the information revealed on automation do not resemble a live pore (Tafazoli *et al*., 2013).

It was noted that perspiration patterns of pores were observed only in live fingers and this suggested the use of pore frequency of fingerprint as a static feature (Derakhshani *et al*., 2003).In a single fingerprint image, more than 1400 pores can be found. Only 20 to 40 pores are necessary for fingerprint identification purposes. Therefore, the pore's centroid-based matching approach may prove to be more effective for improving the accuracy of a fingerprint identification system in the field of Human Biology and Forensic Sciences (Malathi *et al*., 2010).

Poroscopy and its supplementations are of paramount importance in the progress of research that involves Human Biology, local and regional planning, identification of special

gene related illnesses and affected populations, resistant or sensitive genes and subjects related to medical and biological anthropology. Its uses may be extended to another discipline such as social science and police science (Tafazoli *et al*., 2013). It is noteworthy that different methods are employed in the analyses of dermatoglyphic characteristics including ridge pore. This limits the comparison between the results. However, a certain level of analogy may be adopted with caution in making aconclusive Statement.

2.3 FACIAL PROFILES

2.3.1 Techniques Used in Capturing Facial Profiles

In a broad context, the methods used to measure anthropometric dimension facial profile inclusive can be divided into direct and indirect methods (Wickens *et al*., 2004; Hsu *et al*., 2005). In the direct methods, the instrument used are sliding caliper, measuring tape etc, for metric measurement require direct contact with the subject and direct reading of the instruments in use. This method has been in used for assessing the dimensions, location, and level of the facial variables such as external ear in human subjects and for patients who have had plastic surgery (Farkas, 1981).

The practical advantage of this approach is inexpensive and non-invasive nature of the methods. However, the measurements are often necessary to be repeated at least two times by the same investigator in order decrease the chance of error. In addition, the methods are time-consuming and requires strenuous physical circumstances of the information gathering process. In some variables example ear, nose, lips sometimes, the measurement may be

difficult as the distortion of soft tissues may occur during the measurement and the problem of alteration of the operator's perspective due to inability subject to maintaining the orientation of the head for several minutes (Alexander and Laubach, 1968).To overcome some of the limitation encounter in the direct anthropometry, the indirect methods was introduced.

The methods simply involve measurements of a subject without the need of his or her presence. The methods include theuse of projection, photography, scanning dimensions of measurements or reference landmarks from images or electronic files, and transform data using scales or mathematical computations of the relevant reference symbols to obtain anthropometric measurements. Transparent grid board that has already shown the size, photogrammetry and perspective are used as an anthropometric system (Liu *et al*., 2010). It was documented that anthropometric measurements such as upper face height, intercanthal width and nose height available on the face can be gauged with photogrammetry (Nechala *et al*., 1999).

The advantages of photogrammetry or optical scanning alone include indirect contact with the human, ability to obtain dimensions by relatively short examination time for subjects, provision of room of relaxation to the subject because of easy data collection; ability to reviewed or re-measured the images or electronic files as needed etc (Coward *et al*., 1997). In the indirect methods, software and hardware used are more expensive; need for higher level of technical skill for installation, use and maintenance of the equipment; limited

mobility and strict control are always the requirements for maintenance of environmental conditions of the equipment; during the procedures some areas of the body must be covered, making landmarks in the area more difficult to pinpoint for easy measurement. Thus, images may require correction or re-processing (Liu *et al*., 2010).

Another important aspect of anthropometry is the reliability of a measurement. The degree of reliability between the direct and indirect methods was assessed. For example, it was reported that direct and indirect (scanning from a photocopier and digital photographs) measurement, all had anexcellent degree of reliability (Liu *et al*., 2010). It is very clear that each dimension obtained from the subject is according to a regular measurement procedure such as identification of landmarks, measuring, confirming and recording(Liu *et al*., 2010). However, it was noted that consistency in the measurement increased as the number of measures decreased, the amount of subcutaneous tissue decreased, the experience of the measures increased, and as the landmarks were more clearly defined (Gavan, 1950). Changes in posture between measurements are also other source of inconsistent results (Feathers *et al*., 2004).

Although the reliability of the three measurement methods showed an excellent degree of consistency, the direct measurement technique was prone to higher values as compared to the scanning and photogrammetric techniques. For this to be achieved the image must be of excellent quality from photo capture (Liu *et al*., 2010). Considering advantages attached to indirect methods, several techniques were developed and promoted. Nowadays the indirect

measurement involves quantification and mapping of facial features using three-dimensional imaging techniques. Despite advances in three-dimensional imaging techniques and its advantages over two-dimensional techniques, the majority of clinicians and other authorities still rely on two-dimensional techniques for several reasons including cost, accessibility, portability, and ease of use (Inoue *et al*., 1995; Nechala *et al*., 1999).

It was suggested that for the purpose of generating digital photographs (two-dimensional image), it is no surprise that the digital camera is best (Nechala *et al*., 1999). Some of the reason may include the evidence that a photograph (using adigital camera) taken, can be viewed immediately and discarded right away. The photographs are easily downloaded to a computer where they can be viewed, manipulated, edited, and stored. With recent advances in printer technology, digital pictures can be turned into hard copies of very high quality. Sitting of landmarks on an image captured by a digital photograph technique has been shown to be accurate in identifying landmarks of the facial profile. From the viewpoint of practical implications, thedigital camera is thus very feasible for use in anthropometry. It also should be noted that the field of digital photography is changing very rapidly, with technologic advancements resulting in higher quality digital photographs (Liu *et al*., 2010).

2.3.2 Linear Facial Dimensions

The facial anatomy of the different ethnic groups must be well understood to achieve maximum facial aesthetic results after plastic/orthognathic surgery. The knowledge of the most striking facial characteristic of each ethnic group is a stepping stone for the

preparation of corrective surgery or analysis of postoperative as well as characterization of individuals in the context of Human Biology. In the field of facial anthropometry, Farkas and coworkers had compiled the single most comprehensive survey of ethnic groups from multiple regions around the world (Farkas *et al*., 2005). Despite this comprehensive approach, the global range of variation for each facial measurement was not well documented (Fang *et al*., 2011).

Inter-ethnic variability among the facial variable from a review, comprising 27 different ethnic groups of five principal racial groups (European, African, East Asian, South Asian, Native American) that span all inhabited continents, except for Australia and South America, were conducted (Van de Graaff, 2001; Fang *et al*., 2011). The lowest level of facial variation was found in the midface widths, zygion-zygion (zy-zy) and exocanthion-exocanthion (ex-ex) along with the lower face width gonion-gonion (go-go). The forehead height (tr-n) was observed to have thegreatest degree of variation, which recorded the higher degree of variability than any measurements except endocanthion-endocanthion (en-en) (Fang *et al*., 2011).

Among Africans, astudy on afacialvariable on Nigerian established some reference data. In both males and females respectively, the facial height of 12.28 and 11.77 cm; 4.50 and 4.48 cm; 2.44 and 2.03 for maxillary height; 4.49 and 4.023 cm for mandibular heights; and 6.90 and 6.32 cm were documented (Didia and Dappa, 2005). A study of the facial and nasal length of Igbos (adult subject) showed some level of sexual dimorphism with 12.22 ± 2.11 cm and 11.19 ± 0.84 cm as an average facial length for males and females respectively. For

the nasal height, males had 4.87 ± 0.84 cm and 4.40 ± 0.76 cm for females (Olotu *et al*. 2009). Oladipo *et al*. (2008) studied the cranio-facial dimension among adult Ijaw and also observed a significant gender difference, with higher mean found in males. African-American males also had shorter nasal length, wider alar width compared to the white man (Porter, 2004).

In Turkish adults, the mean value of the nasal height in males (53.14 mm) was similar to Chinese (53.50 mm) (Aung *et al*., 2000) and American-Caucasian mean values (53.2 mm) (Farkas, 1994). For females, the mean nose length (50.36 mm) was the same as in Malaysian Indian (50.4 mm) (Ngeow and Aljunid, 2009). But it is longer than the nose length of American Caucasian females (49.2 mm) (Farkas, 1994). In another region of Turkish adult, example Black sea region nose length have long nose as their characteristic feature (Karaca *et al*., 2012). It was reported that face length, face width, and lip length were significantly different among ethnic groups of US workers. In comparison, African-Americans have different face length and lip length from Caucasian, Hispanics, and other race/ethnic groups. Moreover, face width of African-Americans, Hispanics, and others were all significantly different from Caucasian race group. Females significantly differ from male counterparts in a reasonable number of facial dimensions (Zhuang *et al*., 2004).

The morphological and metric assessment of the head and face of 900 male subjects from Italy, Germany, and Lithuania revealed significant differences between the country populations (Ritz-Timme *et al*., 2011). Similarly, the comparisons between the facial measurements of the males from the present study and those relative to North American

Caucasians, American-Africans and Chinese male population (Porter and Doran, 2000) support the findings of the differences observed in head and facial anthropometry between Czech and German males (Hajnis *et al*., 1994). In contrary, certain facial features show no sexual dimorphism, while in other the differences is in favor of the female. Upper and lower lip height were reportedly higher in thefemale. While in upper face width, eye-fissure width, forehead height I and II no sexual dimorphism exist (Karaca *et al*., 2012).

It is a known fact that racial and ethnic differences in the facial traits exist among American and European Caucasians, Afro-Americans, Malaysians, Indians, Arabians and Chinese (Farkas, 1994; Ofodile and Bokhari, 1995; Farkas *et al*., 2005; Ngeow and Aljunid, 2009). However, comparison of twenty-three anthropometric measurements of Turkish young adults population with those reported by Farkas, 1994 for American–Caucasian adults, Ngeow and Aljunid (2009) for Malaysian Indian people. The mean result of biocular width (ex-ex) (96.51 mm in the females, 99.74 mm in males) in Turkish was higher than Malaysian Indian (89.4 mm in thefemale, 92.1 mm in males) and American–Caucasians (87.6 mm in thefemale, 90.7 mm in males).

In addition, the eye width is also greater in Turkish adults than from American–Caucasians and Malaysian Indians (Karaca *et al*., 2012). However, the nasal width (al-al) (32.32 mm in female, 35.15 mm in male) is shorter than African-Americans (43.5 mm) (Ofodile and Bokhari, 1995), Chinese (Aung *et al*., 2000) (39.20 mm), Japanese (36.3 mm) (Ochi and Ohashi, 2002), Canadian-Caucasians (36.9 mm) (Farkas *et al*., 1998), African (45.9 mm) (Ofodile *et al*., 1993), Malaysian Indian (37.4 mm) (Ngeow and Aljunid, 2009) and bigger

than American Caucasians (31.9 mm in females, 34.8 mm in males) (Farkas, 1994). For Asian and Black populations the nose was extremely significantly wide in both sexes (Farkas *et al*., 2005).

It was noted that width of the mouth, width of the philtrum, lip height and lip volume (calculated for upper, lower and both lips) all showed statistically significant sex differences, with males having larger values than females as age advanced. However, the vermilion height to mouth width ratio was larger in females compared to males (Sforza *et al*., 2010). For all ear dimensions in adults, there was a statistically significant sex difference with males yielding measures larger than females (Sforza *et al*., 2009).

Comparison confirmed that in African-American females, the mouth width was greater and ear length was shorter than that of white American females. Although some of these measures have a difference of only 2 mm, the overall composition of the values yield differences in appearance. Similarly, special head height was shorter for African-American women, the fore-head heights I and II, ear length and eye fissure width were greater, but, facial width was not significantly different between groups (Porter and Olson, 2001).

It was evident that different populations show specific morphological and metric facial characteristics which may be useful in the establishment of human biological data, such as ancestry and ethnicity (Ritz-Timme *et al*., 2011).

2.3.3 Facial Angles

The surface projection of certain facial features was also appreciated in the literature among different populations. The facial angles were the common parameters used in this regards. The angular measurement such as naso-frontal, naso-facial, naso-mental, and mento-cervical have also been used to provide an insight into an ideal facial profile (Powell and Humphreys, 1984). In addition, the analysis of the soft tissue facial profile from photographic records provides information on the morphology of the profile and its relationship with the underlying dentoskeletal tissues (Fernández-Riveiro *et al*., 2003) as the extensive evaluation of angular relationship are essential in soft tissue profiling since not all facial traits directly follow the underlying dento-skeletal profile (Subtenly, 1959). Variation in the angulation of the soft tissue facial profile among thedifferent populations has been properly documented.

In the north Indian adult population (Reddy *et al.,* 2011), the mean value of naso-frontal angle (136.7± 3.64 in males and 144.33± 1.75in females)varied from those of Europian adult Caucasians (138.57± 6.81^0 in males and 141.98± 6.06^0 in females) (Fernández-Riveiro *et al*., 2003) and Croatian-Caucasians (136.38±6.71^0 in males and 139.11± 6.35^0 in females) (Anic´-Miloševic *et al*., 2008), Turkish population (146.03 ± 8.19^0 in males and 148.61± 6.66^0 in females) (Malkoc *et al*., 2009), Adult Urhobos of Nigeria (Oghenemavwe *et al*., 2010) (117.75 ± 9.07^0 for males, 127.35 ± 9.50^0 for females). With female having greater mean values and significantly differ from amale in all population. Epker (1992) in a study on frontal and lateral facial views of Caucasians found no gender differences in this

angle (130 degrees). The reason for this variation was attributed to glabella, which is more prominent in some populations (Oghenemavwe *et al*., 2010).

With regard to cervicomental angle, the north Indian adult population mean values (100.93± 1.77 in male and 94.11±1.37 in female) was reported to be higher compared to European adult Caucasian (79.85±7.19 in male and 84.18± 6.65 in female) (Fernández-Riveiro *et al*., 2003) and Urhobos of Nigeria (93.33±3.27in male and 90.88±3.58in female) (Oghenemavwe *et al*., 2010) and less compared to Turkish population (104.86± 9.86in male and 95.64± 7.74in female) (Malkoc *et al*., 2009). A significant sexual dimorphism was noted in north Indian adult population which suggested that the males have more prominent chin compared to females (Reddy *et al.*, 2011).

For naso-mental angle, variation was also observed; North Indians (127.71± 1.97 in males and 127.11± 1.81^0 in females) (Reddy *et al*., 2011), Croatian Caucasians (130.47± 3.73^0 in males and 130.19 ± 3.47^0 in females) (Anic´-Miloševic *et al*., 2008) and Urhobos of Nigeria (121 .95 ± 7.93^0 in males and 126.55 ± 6.93^0 in females) (Oghenemavwe *et al*., 2010). For the naso-facial angle, the north Indian (34.38± 0.77^0 in males and 33.69 ± 1.37^0 in females) (Reddy *et al*., 2011) recorded higher mean compared to Croatian-Caucasians (29.53 ± 2.51^0 in males and 30.36 ± 2.38^0 in females) (Anic´-Miloševic *et al*., 2008), but less (40.77 ± 6.29^0 in males and 35.60 ± 7.46^0 in females) compared to Urhobos of Nigeria (Oghenemavwe *et al*., 2010). This can be due to the fact that white European population has less protruded nose than the north Indian. No significant gender differences are observed in the two populations (Reddy *et al*., 2011). Among the Igbo male population, the

degree of variability among four aesthetic angles; naso-frontal, naso-facial, naso-mental and mento-cervical angles were reported. Naso-frontal variability was observed to be the largest angle with a mean value of 134 and followed by the naso-mental with a mean value of 126 then mento-cervical with amean value of 99 and the least was naso-facial with a mean value of 39 (Ukoha *et al*., 2012).

In frontal profile, the angle related to the aesthetically pleasant facial profiles include facial symmetry angle, gonion angle, facial aperture modified angle and nasion angle. The study among Brazilians and Caucasians, showed that the facial aperture modified angle was lower in the esthetically unpleasant group (42.92 ± 2.42^0) and higher in the pleasant group (44.88 ± 2.12^0). Lower values for this angle may be linked to longer and thinner face (Morosini *et al*., 2012). The nasion angle, the pleasant group, have intermediate values (69.98 ± 1.97^0) between esthetically unpleasant and accepted groups, similarly indicating a tendency for horizontal facial growth for individuals composing pleasant group (Ackerman and Proffit, 1997). For the other two types of angles, facial symmetry and gonion angles (which was used to access the symmetry) showed no difference between three groups; aesthetically pleasant, unpleasant and accepted (Morosini *et al*., 2012).

2.3.4 Facial Proportion

Founder effect or genetic drift as one of the evolutionary forces, resulting in reproductive isolation and reduced genetic diversity may have led to the ethnic variation in the facial appearance. It was also suggested that through sexual selection, individuals with

anattractive facial profile may have been more likely to reproduce and pass on such traits to subsequent generations (Buggio *et al*., 2012). Human sculptures produced in ancient Greece were said to be derived from proportions that followed established rules or 'canons' (Edler, 2001). These rules were incorporated to the ''neoclassical canons'' for the human face (Farkas *et al*., 1985; Le *et al*., 2002). These canons were based on the assumption that certain fixed ratios existed between different parameters of a harmonious face. Subsequently, these canons were adopted by medical artists, anatomists and aesthetic surgeons (Farkas *et al*., 1985).

North American Caucasians were the first population upon which applicability of neoclassical facial canons was tested (Farkas *et al*., 1985). Subsequently, the applicability of these canons was also tested on several other population groups such as African-Americans (Farkas *et al*., 2000), Turkish (Borman *et al*., 1999), Vietnamese, Thai (Le *et al*., 2002), Chinese individuals (Wang *et al*., 1997; Le *et al*., 2002) and Southern Chinese (Jayaratne *et al*., 2012). Comparison of African-Americans and North American Caucasians revealed that the three sections of the facial profile were not equal in either population. In African-American sample, it showed the prevalence of the long lower face height also in relation to the height of the forehead. In horizontal canons of the orbital regions, the similarity between the two populations was demonstrated by the great frequency of intercanthal spaces to be wider than the length of the palpebral fissures (Farkas *et al*., 2000).

It was also reported that these canons served as criteria for determining the differences between the Asians and Caucasians. It was noted that a different existed in the facial profiles between Asians and Caucasians. The validity of the five other facial canons was more frequent in Caucasians (range: 16.7-36.7%) than in Asians (range: 1.7-26.7%). Horizontal measurement results were significantly greater in the faces of the Asians (en-en, al-al, zy-zy) than in their white counterparts (Farkas *et al*., 2000; Le *et al*., 2002).

Study on different ethnic groups has established that the frequency of valid canons was greatly surpassed by their variations. This indicates that other than the canon the variant can be used to compare different populations and sexes within the same population. For example in Hong Kong Chinese population, the variant in the orbital canon with a wider intercanthal distance (en-en>en-ex) was found to be 100%, remarkably higher than the 51.5% observed in North American Caucasians (Farkas *et al*., 1985). The frequency of this variant in Singapore Chinese (Le *et al*., 2002) was similar to Southern Chinese (Jayaratne *et al*., 2012). A relatively narrowmouth with wide-nose variant of the naso-oral canon [ch-ch < 1/2(al-al)] was common among all the East Asian ethnic groups and the African-Americans (Farkas *et al*., 2000), whereas its converse variant [ch-ch > 1/2 (al-al)] was prevalent among North American Caucasian adults (60.2%) (Farkas *et al*., 1985). The applicability of the orbital and naso-oral canon was much higher in the sample from Mainland China (Wang *et al*., 1997), compared to Hong Kong and Singapore Chinese (Le *et al*., 2002). In addition, the en-en > al-al variant of the orbitonasal canon was more prevalent among the Southern Chinese (73.8%), whereas its converse variant (en-en <al-al) was common among the Central Mainland Chinese (34.5%) (Wang *et al*., 1997) and

Singapore Chinese (48.3%) (Le *et al*., 2002). Within the ethnic group analyses, significant gender differences in relation to the frequency of facial three-section and the orbito-nasal canon were found among Southern chines population. The proportion for facial three-section was; males have 51.9% and females have 49% and for orbito-nasal canons; males have 90.4% and females have 56.9% (Jayaratne *et al*., 2012).

The facial three section canon (tr-n= n-sn =sn-gn) and the orbital canon (en-en =ex-en) could not be found even in a single participant. The orbitonasal canon (en-en = al-al) was the most frequently supported, with a 19% prevalence and least was in naso–oral canon, with 8.7 prevalence in the whole sample of Southern Chinese faces (Jayaratne *et al*., 2012). In addition, the comparison between male and female African-Americans showed significant different level of occurrence of canon between the sexes. In African-American, males only canon, I and VI have been established with the prevalence of 2.8% and 11.9%, respectively. In the rest of the cannons (II, III, IV, V, VIII, IX) indicate thedominance of one variant with more than 95% in general. But in canon VII the two variants share the proportion some how equally (Poter, 2004). It was reported that African-American females have small prevalence of canon I, IV, V, VI, VII, VIII and IX with the percentage of 13%, 7.4%, 4.6%, 30.6%, 7.4%, 9.3% and 3.7%, respectively. Canon II and III were absent also in the female population (Porter and Olson, 2001).

2.4 ASYMMETRY IN FINGERPRINT AND FACIAL PROFILES

2.4.1 Overview of Asymmetry

Asymmetry indicates a failure of an identical development on both sides of the body of an individual (Kusuma *et al*., 2001). It is measured as the right minus the left value of the bilaterally paired trait. Three types of biological asymmetry: fluctuating asymmetry, directional asymmetry, and antisymmetry exist at thepopulation level. Fluctuating asymmetry (FA) is simply referred to the small random deviations from perfect bilateral symmetry. These small random deviations result in a normal or leptokurtic distribution of asymmetry around a mean of zero. Directional asymmetry (DA) on other hand, refers to symmetry distribution that is not centered around a mean of zero but is biased significantly, towards larger traits either on the left or the right side. The third type of symmetry, antisymmetry (AS) is characterised by being centred around a mean of zero; however, symmetric individuals are rarer than those seen in fluctuating asymmetry distributions, such that the distribution is platykurtic or, in the extreme, bimodal. Directional asymmetry and antisymmetry are developmentally controlled and therefore likely to have adaptive significance. Fluctuating asymmetry, on the other hand, is not likely to be adaptive as symmetry is expected to be the ideal State (Van Valen, 1962; Palmer, 1994; Gangestad and Thornhill, 1999).

2.4.2 Asymmetry in Fingerprints Profiles

Asymmetry in homologous regions of fingers and palms of humans for various aspects of dermatoglyphics was documented (Cummins and Midlo, 1943). Based on the basic pattern type of fingerprints, a significant bilateral difference among a region of Andhra Pradesh

(Indian) population was reported. Whorls were slightly more frequently observed on the right hands. Radial loops and arches were more common on the left index finger than on the right one. Arches were more frequent on the left middle finger compare to right one (Sangam *et al*., 2011). In addition to pattern type asymmetry, it was reported that a clear ridge count asymmetry exists between homologous fingers. The asymmetry is then attributed to environmental effects operating at early intrauterine life during the development of epidermal ridges (Holt, 1954). It was concluded that asymmetry provides some insights into the genetic and developmental nature of dermatoglyphics (Jantz, 1979) as well as alittle hereditary influence (Singh, 1970). Hence, in population variation and characterisation study, ridge count asymmetry may be considered as an important dermatoglyphic marker (Kusuma *et al*., 2001).

Population study indicates variation finger ridge asymmetry in human population. In Indian population variance of asymmetry was reported and pointed out that the endogamous groups of India are highly heterogeneous and present significant range of variation can be explained by several factors including environmental and developmental stress (Malhotra, 1987), homeostasis disturbance in utero (Reddy *et al*., 1991; Jantz and Brehme, 1993). Another study among four tribal populations of Andhra Pradesh, India, shows that the mean DA follows a decreasing order from radial to ulnar side, and the thumb records higher bilateral asymmetry and large individual variation than any other finger. A similar observation was recorded inprevious studies on other Indian populations (Malhotra *et al*. 1991). The sexual dimorphism is not significant in both mean DA and means absolute asymmetry (AA), except in the fourth finger for mean AA (Kusuma *et al*., 2001). It was

also evident that males had a higher ridge count and breadth than females, which was associated with a higher rightward DA in the ridge counts (Karlik and Novotny, 2003). This led to thesuggestion that sex chromosomes may be a factor influencing ridge counts as it reported to affect the size of the cells (Bosco *et al*., 2001). However, theabsence of asymmetry in minutiae count, reported for Japanese and German subjects (Okajima 1966), was confirmed a year later by the same author on Japan population (Okajima 1967).

For ridge density, astudy in central Indian population reported that the ridge density in the thumb fails to show asignificant level of asymmetry (Kapoor and Badiye, 2015). This is in contrast to other studies (Ohler and Cummins, 1942; Cummins *et al*., 1994) in which the ridges of theright hand were found to be coarser than the left hand. Thus, for the same area, the right hand would have fewer ridges than the left hand. Moreover, it was evident that ridge density in both sexes among Spanish Caucasians population is greater in the areas of the left hand, thus showing finer ridges than in the right hand. These differences were statistically significant in the radial and ulnar areas, but not in the lower area of the finger (Gutie´rrez-Redomero *et al*., 2008). It was also observed that mean ridge breadth is greater for right fingers than for left fingers, and these differences are statistically significant for digits I–III and when all digit measurements are pooled for each hand.To evaluate further the specific inter-digit differences, a Bonferroni post-hoc test found statistically significant differences between all fingers, except left and right digits II and III and digits IV and V (Mundorff *et al.,* 2014).

To be specific certain dermatoglyphic areas likeathumb and interdigital area a-b are more prone to developmental/environmental insults compared to other areas. This suggested that these two areas are abetter indicator of stress in an individual or population (Malhotra *et al*., 1991). Several disease conditions like congenital vertebral anomaly (Goldberg *et al*. 1997), developmental disorders (Naugler and Ludman 1996), schizophrenia (Mellor 1992), down syndrome (Davee *et al*. 1989), hypospadias (Micle and Fried 1980), cleft lip (Woolf and Gianas,1976; Woolf and Gianas, 1977), were linked to the disturbance in the symmetry. The findings by Jantz (1979) show that asymmetry in the thumb is thedirectional type.

In addition, the level of homozygosity was observed to increase the degree of asymmetry. It was found that individuals, who are more heterozygous at loci determining five independent morphological traits, have reduced FA of their ridge counts (Livshits and Kobyliansky, 1987). It was also reported that there were negative associations between asymmetry and heterogeneity (Parson, 1990). It should be noted that when the pattern of asymmetry is consistent among thedifferent ethnic groups, the underlying mechanisms influencing the level of asymmetry should be similar for all groups (Kusuma *et al*., 2001).

It was concluded that about 80% of individuals have more dermal ridges on the right. The frequency for the minority pattern with more ridges on the left was higher in females. In addition to the sex difference in DA, a total number of ridges on the two hands differs for the sexes. Males tend to have greater ridge count (Holt, 1968; Green and Young, 2000). It was also noted that asymmetry was greater in stressed offspring than in those that were

unstressed (Newell-Morris *et al*., 1989). The asymmetry of fingerprint ridges originates in the first trimester of pregnancy and remains unchanged thereafter. Leftward asymmetry (more ridges on the left) occurredmore frequently in females (Green and Young, 2000).

2.4.3 Asymmetry in Facial Profiles

In abroad context, the human form has been considered to be externally symmetrical and internally asymmetrical. However, small differences between the dimensions of the left and right halves of the face may occur in normal individuals, which singly do not normally result in an aesthetically unpleasing appearance of the face (Ferrario *et al*. 1995; Ferrario *et al*. 2001). In the simple note, symmetry and balance can be explained as the State of facial equilibrium, correspondence in size, shape and arrangement of facial features on opposite sides of the median sagittal plane. Facial asymmetry can be said to result when one side of the face is larger than the other (Smith, 2000). Therefore, proper evaluation of asymmetry depends on the accurate establishment of the horizontal and vertical reference planes in relation to the facial midline, which serves as the origin for measurements (Ras *et al*., 1995). Facial symmetry has been considered as one of the factors in attractiveness (Baudouin and Tiberghien, 2004).

Although literature reports have also found asymmetry as a normal facial feature, there is no clear-cut agreement with regarding the degree, side and spatial localization of facial asymmetry (Ferrario *et al*. 1995; Shaner *et al*. 2000; Ferrario *et al*., 2001). It was suggested that the normal limits of soft tissue asymmetry in the measurements taken from the upper

and middle regions of the face should not exceed 5 mm in males and 6 mm in females as a general rule (Shaner *et al*., 2000). It was also noted that the differences between the most symmetric and the most asymmetric groups were less than 2.5 mm (Ferrario *et al*., 2001).

The side of the face that dominates in the manifestation of the symmetry has receives some level of attention in the literature. Some studies observed that left side of the face is more dominant (Vig and Hewitt, 1975; McIntyre and Mossey, 2002; Bakholdina, 2007; Ercan *et al*., 2008; Haraguchi *et al*. 2008; Balueva *et al*., 2010). It was suggested that the left side of the face is more expressive of emotions (Sackeim *et al*., 1978; Indersmitten and Gur, 2003). Such a functional asymmetry in facial expression may have some relationship to the dimensional balance between the left and the right hemiface (Haraguchi *et al*. 2008). In another study, the right side of the face is more dominant (Farkas and Cheung, 1981; Ferrario *et al*. 1994, Ferrario *et al*., 1995, Ferrario *et al*., 2001; Shaner *et al*. 2000; Simmons *et al*., 2004). However, it was later noted that as the growth stage proceeds, right-sided dominance becomes less frequent, whereas left-side dominance becomes more frequent (Haraguchi *et al*. 2008).

Analyses of facial asymmetry based on the different regions of the face show that the symmetry is region dependent. Farkas and Cheung (1981) found that the most asymmetric part of the face (69.2%) was the upper third. For Ferrario *et al*. (1994), the asymmetry is more evident in the middle (tragus) and lower (gonion) thirds of the face. It was also observed that the measurements that involve tragion and gonion to the mouth and chin

regions recorded much higher normal variability (Shaner *et al*., 2000). Many studies support the idea that asymmetry in the lower third of the face was greater than in the middle and the upper thirds (Severt and Proffit, 1997; Shaner *et al*. 2000; Haraguchi *et al*. 2002). It has since been documented that the response of functional adaptation to asymmetrical masticatory activity is the main cause of asymmetries in the lower part of the face (Vig and Hewitt, 1975).

Similarly, it was pointed out that facial asymmetry is more obvious when moving downward on the face (Huang *et al*., 2013). This is also in line with previous studies (Peck *et al*., 1991; Ferrario *et al*., 1993; Farkas, 1994; Ras *et al*., 1995; Ferrario *et al*., 1995). Moreover, less asymmetry and more dimensional stability were noted as the cranium is approached (Huang *et al*., 2013). In another study, it was noted that asymmetry is also greater at least in the maxillo-frontal region (Balueva *et al*., 2010). According to Ercan *et al*. (2008),the most asymmetric part of the face is the middle third of the face (maxillary bone, zygomatic corner, and lower orbital border). However, asymmetry in the lower facial third is seen mainly in females. On the contrary, Bakholdina (2007) observes the tendency toward greater asymmetry of the supraorbital margin compared to the infraorbital margin.

An inspection of the literature on sex differences in asymmetry provides different reports. Hallgrımsson (1999) reported that based on craniometric no gender differences exist. Similarly, little or no sexual dimorphism was noted in odontometric variables (Bailit *et al*., 1970; Noss *et al*., 1983; Guatelli-Steinberg *et al*., 2006). However, when examining facial FA only, it was reported that the asymmetry in male faces was higher than those in female

faces. But there is little evidence to support a higher level of developmental stability in females than males (Simmons *et al*., 2004; Ozener and Fink, 2010). However, according to Ercan *et al*.(2008), the number of significantly asymmetric linear distances between the two halves of theface was greater in females. Based on the type of asymmetry, 12 of 35 traits (34%) in male faces also had the characteristic of FA. The remaining 66% of traits exhibited DA. For female faces, seven of 35 traits (20%) had properties of FA. The remaining trait exhibits DA (Simmons *et al*., 2004).

To better explain the basis of the gender differences, it was reported that the tendency of the males to be asymmetrical may be linked to the increase in the environmental stresses. It might be that environmental stress, such as poor living conditions, may affect males more strongly than females, because in many species including human males tend to be more vulnerable compared to females (Ozener and Fink, 2010). Some studies used a composite measure of bodily fluctuating asymmetry to establish the gender differences. For instance, Trivers *et al*. (1999) found significant sex differences in a composite measure of body asymmetry in Jamaican children with girls being more asymmetric than boys, particularly in the elbow and fourth digit. A similar result was obtained by Gray and Marlowe (2002), who reported females as being more asymmetric compared to males.

2.5 FINGERPRINTS, FACE AND OTHER BODY VARIABLES

2.5.1 Relationship of Fingerprint Profile with Other Body Variable

Establishment of arelationship between variables in the field of biological anthropology has long been considered as one of the criteria for personal identification. This may have potential in narrowing down the investigation process, and thus provides useful clues to expert. In addition, this can provide concepts useful in human characterization. With regards to fingerprints, interdigit fingerprint correlation was well documented in the literature. The correlation variation ranged from 0.07 to 0.57 in males and from 0.12 to 0.59 in females, with thehighest correlation found between the pair of the right and left finger II–III and in females (0.59) between IV and V, respectively.The first digit has the least correlation with the other fingers, except for its correlation with its own homologue (Karmakar *et al*., 2008).

The epidermal breadth was also reported to vary considerably among different dermatoglyphic topological regions and between the sexes. It was further suggested that there is a common biological regulatory mechanism between ridge breadth and certain body dimensions such as weight, height, and size and width of a hand (Ohler and Cummins, 1942). To evaluate the influence of body size, correlation coefficients were determined between ridge breadth and weight, stature, and BMI. The literature indicated that weight correlated more with ridge breadth ($r = 0.41 – 0.48$) than stature ($r = 0.36 – 0.43$). Correlation with BMI is the lowest ($r = 0.15 – 0.23$) and this only explains thesmall amount of ridge breadth variation. This led to consideration of stature, weight and BMI as confounding variable when dealing with fingerprints' profiles including ridge breadth

(Mundorff *et al*., 2014). This is evident by the fact that fingertips, and associated profile, continue to grow in size until maturity (Holt, 1968; Loesch, 1983). It is also noted that the evidence of arelationship between weight and ridge breadth is enough reasoning of misclassification of larger females and smaller males (Mundorff *et al*., 2014).

To explore more on therelationship of fingerprint profiles, it was suggested that the size of foetal fingerprints, when compared with a neighbouring finger on the same hand, could be influenced by factors stimulating or inhibiting growth along an axis of development extending from the brain to the lower limbs (Kahn *et al*., 2001). It has also been demonstrated that a correlation existed between epidermal ridge development and development of the skeleton of hand in foetuses. The breadth of the primary ridge is related to general palm size, and other hand dimensions, especially the length of the metacarpal. In addition, the interridge breadth found to correlate significantly not only with metacarpal length, but also with overall skeletal size and dermal thickness around the distal phalanx of individuals (Babler, 1990).

In another note, each fingertip is related to a spinalcord segment in a range that includes the sixth through the eighth cervical levels (C_6 – C_8). The cephalad (upper) side of C_6 is related to the thumb (first finger), and the caudal (lower) side of C_8 is related to the little (fifth) finger (Heimer, 1994; Kahn *et al*., 2001). An association of the differences in the ridge count between finger and body variable was established. It was reported that among the 20 possible ridge-count differences evaluated in an anthropometry study, only dR45

(differences between the right fourth and fifth fingertips) was significantly associated with waist circumferences to hip ratio (WTR). The ridge-count difference, (between the right first and fifth fingertips) also demonstrates the strongest association with WTR. This provides information that the ridge count difference between adjacent fingers associated positively and negatively with waist circumference and mid-thigh circumference respectively (Kahn *et al*., 2001).

2.5.2 The relationship of Facial Profile with Other Body Variables

Modern psychologists eschew the belief that face can be used as a platform for reading acharacter from an individual. Aristotle was reported as one of the ancient philosophers who described at length the facial signs of strength and weakness, genius and stupidity, timidity, and boldness (Berry and McArthur, 1986). The same may be applied to anthropometric characters such that the facial features may be used to assess other body variables. For example, estimation of height from the various body parameters was established (Krishan, 2008a,b ; Rastogi *et al*., 2008; Raxter *et al*., 2008). As it is well known all these parts of the body and bones may not always be available for analyses. It becomes necessary to make use of other parts of the body like head and face region for the purpose of establishment of identity (Krishan, 2008b). This stimulates another scientists to embark on the establishment between stature and facial variables. A correlation between height and cranial diameters among Italian population and proposed amathematical formula for determination of living height was reported (Introna *et al*., 1993). A study of 124 Japanese cadavers successfully estimates the height from anthropometry of the skull and finally, a regression formula for such population was generated (Chiba and Terazawa,

1998). In addition, radiographic lateral cephalogram was used to predict height in central Indian population. A regression formula for estimation of stature from 16 cephalo-facial measurements in a sample of 252 Koli male adolescents in north India was also reported in the literature (Patil and Mody, 2005). Maximum head length, maximum head breadth, Horizontal circumference of head bigonial diameter, morphological facial length were the selected parameters used in the estimation of theheight of adult male Gujjars of north India (Krishan, 2008b).

Weight and BMI were reported to have arelationshipwith facial features. A study conducted on Caucasian population showed that facial adiposity, or the perception of weight in the face, can predict perceived health and attractiveness (Coetzee *et al*., 2009). In another study (Coetzee *et al*. 2010), the relationship between three facial features: width to height ratio, perimeter to area ratio, and cheek to jaw width ratio with BMI were established. Gender-wise analyses show that these three facial features were significantly related to BMI in males, while theonly width to height ratio and cheek to jaw ratio were significantly related to BMI in females. In addition to the three facial parameters, correlations between four facial features and BMI were also observed among large sample (n = 911) of young Korean population (Coetzee *et al*., 2010; Pham *et al*., 2011).

Using automated approaches, the cheek bone to jaw width (CJWR), width to upper facial height ratio (WHR), perimeter to area ratio (PAR), eye size (ES), lower face to face height ratio (LF/FH), face width to lower face height ratio (FW/LFH), and mean of eyebrow

height (MEH) were used to predict the weight, height and BMI (Wen and Guo, 2013). This is an extension of similar studies on other population which emphasize mainly on the correlation measures between facial features and the BMI (Coetzee *et al*., 2009; Coetzee *et al*., 2010; Pham *et al*., 2011).It was observed that tendency between the facial features and the BMI-dependent on age size, contour and shape of the face among other factors. For instance, in adult participants, a person with a squarer face (CJWR, WHR, PAR, and FW/LFH), smaller eyes (ES), smaller rate between lower face to whole face length (LF/FH), larger eyebrow height (MEH) has larger BMI (Wen and Guo, 2013).

One advantage of predicting height, weight, and BMI from thefacial feature is that the approach is non-invasive. The conventional methods of measuring individual's height and weight in order to compute his or her BMI may be avoided. This can be suggested as an alternative approach for some practical uses, such as on-line photos or surveillance videos of faces, where it is impossible to use traditional method of obtaining BMI (Coetzee *et al*., 2009; Coetzee *et al*., 2010; Pham *et al*., 2011, Wen and Guo, 2013).

2.6 RELATIONSHIP OF FINGERPRINTS AND FACIAL PROFILES

Biometrics can simply be interpreted as anidentification of an individual based on his or her physiological or behavioural characteristics. It, therefore, absolutely have the capability to differentiate between a genuine individual and a fraudulent impostor (Papoulis, 1965; Newham, 1995). Short-term, physiological or behavioural characteristics are used as

biometric indicators to make a personal identity as long as it satisfies the following requirements: universality, uniqueness, permanence and collectability (Jain *et al*., 2004).

The two most popular biometric systems are fingerprint and face recognition systems. The fingerprint is a kind of identity card that people carry with them continuously (Kov'acs-Vajna, 2000). The fingerprint recognition might be broadly classified as being minutiae-based, correlation-based and image-based systems (Lumini and Nanni, 2006).However, it was noted that minutiae-based approach is the best. This approach relies on the comparison of similarities and differences of local ridge attributes and their relationships to make a personal identification (Jain *et al*., 1997; Hong and Jain, 1998)**.**Face recognition, on the other hand, is a biometric method that recognised individuals using facial features. It is an active research area with applications, ranging from static, controlled mug-shot verification to dynamic, and uncontrolled face identification in a cluttered background among others (Hong and Jain, 1998). Facial expression, 3D pose, hair style, makeup, lighting, background, scale, noise, and face occlusion are some of the numerous factors affecting the appearance of an individual's facial features, thus making face recognition process complex and difficult (Cevikalp *et al*., 2005; Bouchaffra and Amira, 2008).

From abiological point of view, it is well established that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment (Jain *et al*., 2002). Physical appearances of faces and fingerprints are also parts of an individual's phenotype. The general characteristics pattern of fingerprint are

determined by the genes (Jain *et al*., 2002). In dermatoglyphics studies, the maximum generic difference between fingerprints has been reported among individuals of adifferent population. Unrelated persons of the same population have very little generic similarity in their fingerprints. Parents and children have some genetic similarities as they share half of the genes, siblings have more similarity; and the maximum genetic similarity is observed in the identical twins, which have the closest genetic relationship (Cummins and Midlo, 1961).

A study analysing the similarities in fingerprint minutiae patterns in identical twin fingers showed that the fingerprints of identical twins is highly correlated. In addition to this high minutiae correlation, other profiles of fingerprints such as ridge count, ridge width, ridge separation and ridge depth are also significantly correlated in identical twins (Jain *et al*., 2002). In the case of faces, the circumstances are very similar to the fingerprints. Because the more related the individuals are the more similar they are in appearance. For example, parents and child have some generic similarity as they share half of the genes, siblings have more similarity, and the maximum genetic similarity is observed in the identical twins, which bears the closest genetic relationship (Sagiroglu and Ozkaya, 2009a).

Several studies examined the correlation among faces and fingerprints of identical twins (Jain *et al*., 2001; Jain *et al*., 2002; Kong and Zhang, 2006; Youssif *et al*., 2007). It was declared that identical twins would cause vulnerability problems in biometric-based security applications, due to large correlation among their biometrics. One of the instances

is that about 95% similarity measure of identical twin fingerprints is reported (Costello, 1999). The same circumstance can be applied to theface. Some of the reasons of this high degree similarity include; firstly, identical twins have identical DNA except for generally undetectable micro mutations that begin as soon as cell starts dividing. Secondly, development of fingerprints and faces of identical twins originate from the same DNA, leading to considerable genetic similarity (Bodmer and McKie, 1994; Jain *et al*., 2001). It is evident that differentiation of fingerprints or faces of different individual is not complex. However, for identical twins, the situation is very difficult and complicated, not only for the eyes and brain of a human being but also for biometric-based recognition systems (Ozkaya and Sagiroglu, 2010). Based on the above discussion, it is clear that identical twins possess strong similarity in both fingerprints and faces. Increasing and decreasing distinctions of such similarities are also the same among non-related individuals. Consequently, this similarity supports the idea that there might be some relationships among fingerprints and faces (Sagiroglu and Ozkaya 2009).

Prediction of one biometric feature from another biometric feature is a challenging idea. This transformation might have potentials for many applications, especially security applications. Based on the literature reviewed, there is scanty information on relationships among the biometric features or obtaining one feature from the others (Ozkaya and Sagiroglu, 2008a; Sagiroglu and Ozkaya, 2009a, Ozkaya and Sagiroglu, 2010). It has been proven experimentally the existences of the relationship among the biometric features of faces and fingerprints. This has led to proposed novel approaches for generating several components of the facial trait. These include the face borders (Ozkaya and Sagiroglu,

2008b); face contours, including face border and ears (Sagiroglu and Ozkaya, 2008a); face models, including eyebrows, eyes and mouth (Sagiroglu and Ozkaya, 2008b); inner face parts, including eyes, nose and mouth (Ozkaya and Sagiroglu, 2008c); face parts, including eyes, nose, mouth and ears (Ozkaya and Sagiroglu, 2008); face models, including eyes, nose, mouth, ears and face border (Sagiroglu and Ozkaya, 2008c); face parts, including eyebrows, eyes, nose, mouth and ears (Ozkaya and Sagiroglu, 2008c); only eyes (Sagiroglu and Ozkaya, 2008d); and the face parts, including eyebrows, eyes and nose (Sagiroglu and Ozkaya, 2009a).

Based on these series of articles by the same authors, it was concluded that an unknown biometric feature can be achieved from a known biometric feature (Sagiroglu and Ozkaya, 2009b). As explained earlier, processing fingerprints and faces are really difficult, complex and time-consuming tasks. Many approaches, techniques, and algorithms have been used for face recognition, fingerprint recognition and their substeps (Ozkaya and Sagiroglu, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 LOCATION OF THE STUDY

3.1.1 Brief Geography and History of Hausa Land

Language over time has been used as one of the markers of ethnic differentiation. From the historical point of view, the Hausa people have been referred to as Hausawa, Haoussa, Ausa, Habe, and Mgbakpa. In the whole of the West African region, they constitute one of the single largest ethnic groups. They are located on a large scale in the Sahelian areas of northern Nigeria and the south-eastern Niger and spread across other African countries(Lenshie and Ayokhai, 2013).

Geopolitically, Hausaland is located in the central Bilad al-Sudan, bordering Kanem Borno in the east and Songhai in the west. The Hausa people were neither an ethnic group nor the only inhabitants of the land. They were believed to have migrated into the region sometime before the 10th century from the central Sahara, perhaps due to desiccation or some such natural phenomenon. On arrival, the Hausa people settled in the central savanna and mixed with the indigenous people. The result was a multi-ethnic society sharing a common language called 'Hausa' (Lenshie and Ayokhai, 2013).The State formations in the Hausaland were not monolithic; they were separate and independent entities. The independence enjoyed by the people also reflected in their pre-Caliphate identity formations. Each Hausa group preferred to be associated with their specific areas of habitation either as Gobirawa, Katsinawa, Daurawa, Kanawa, Zazzagawa and so on (Jega, 1999).

Historically, it is reported that Daura was governed by a queen named Daurama for several decades before the mythological appearance of Bayajida, to whom is accredited the founder of the Hausa "Bakwai" (seven legitimate Hausa) States, and to whose offspring and concubines are attributed the founders of Hausa "Banza Bakwai" (seven illegitimate Hausa States). Some of these States include Nupe, Gwari, Yauri and Kwararafa among others (Buah, 1974). Another important landmark in the history of the Hausa is the migration of the Fulani into Hausaland during the pre-Jihad era. In the century before the Jihad, the north-western Hausaland inhibited by large Fulani, who migrated over the centuries from the Futa-Toro. The majority of them were Muslims, settled in towns and villages and inter-married with the Hausa population (Hunwick, 1965). With this, the tendency for ethno-religious transformation was, therefore, eminent. The migration, hence, provided the tendencies of creating a new ethnic identity (Kazah-Toure, 2004).

Through the Trans-Sahara trade in the middle of 14th century, the Hausaland began to experience widespread immigration by the Fulani and their animals in search of pasture. It was during this period that Islam found its ways into Hausaland (Lenshie and Ayokhai, 2013). However during this period, some of the characteristics of Hausa ethno-cultural identities, such as language and other traditions that were considered not to be in conflict with Islamic traditions were maintained. The essence was that the language already had profound influence throughout the Northern Nigeria, given that it was easy to learn and rich in vocabularies (Okafor, 1989). The Fulani in the Hausaland gave up their mother tongue to adopt the Hausa language, but retained their paternal blood line in traditional governance (Lenshie and Ayokhai, 2013).

3.1.1 Area of the Study and Duration of Data Collection

The study was conducted in one of the Hausa State; that is the Kano State of Nigeria (Figure 3.1). Kano State is the most populous State in Nigeria, with about 9,383,682 million people. It was one of the original seven Hausa city-States in Nigeria. The urban area of the State covers 137 km^2 and comprises six Local Government Areas (LGAs); Kano Municipal, Fagge, Dala, Gwale, Tarauni and Nassarawa with a population of 2,163,225 at the 2006 Nigerian census. The metropolitan area covers 499 km^2 and comprises eight LGAs; the six mentioned above plus Ungogo and Kumbotso with a population of 2,828,861 at the 2006 Nigerian census. The principal inhabitants of the city are the Hausa people (Barau, 2007).

The field collection of the data covered a period of 28 weeks (7 months). The reading and recording of the variables from captured images of thumbprints and faces for analyses covered a period of eight weeks (two months). There was time overlap between the field collection of the data and recording of the variables.

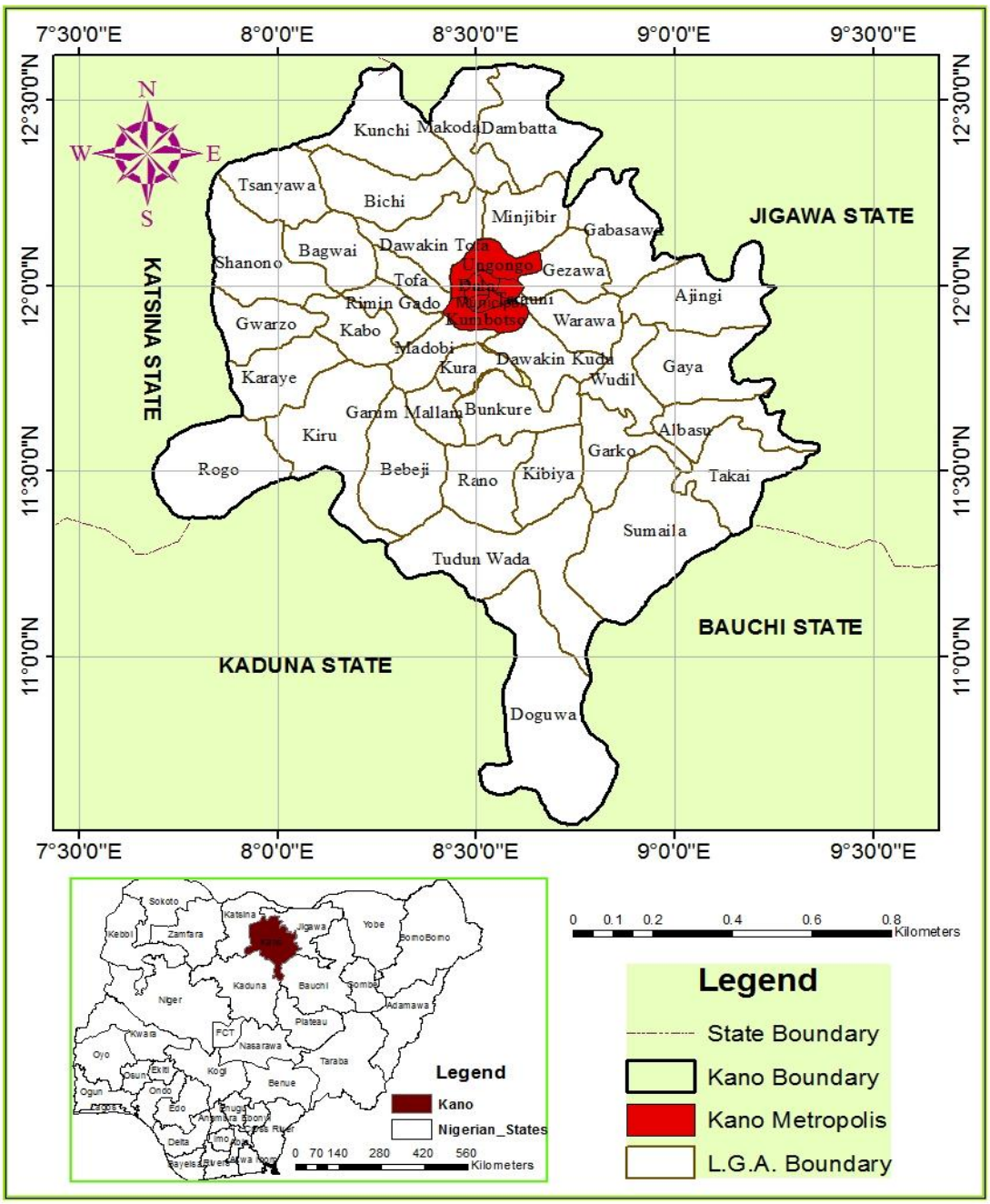


Figure 3.1: Location of the study area (map of Kano State of Nigeria)

3.2 STUDY POPULATION

A total of 534 subjects comprising 398 males and 136 females participated in the study. The minimum sample size needed for the study was 384 which was calculated using a formula (Oyejide, 1991) below;

$$n = \frac{Z^2 pq}{d^2} = \frac{(1.96)^2 \times 0.5 \times (1-0.5)}{(0.05)^2} = 384$$

Where n = desired sample size, Z = confidence level (How confident the actual mean falls within your confidence interval) 1.96 at 95%, p = prevalence/standard deviation (How much variance expect in the responses) 50% (0.5), q = 1 – p, d = degree of precision/ margin of error which is 5%.

The participants were selected using sample random technique.

3.2.1 Inclusion Criteria

The following subjects were included in the study:

i. Any subject who is Hausa up to level of grandparents.
ii. Apparently healthy subjects whose thumbs and face were free from any inflammation, deformity or pathological changes.
iii. The individuals within the age range of 18-25 years was considered.

3.2.2 Exclusion Criteria

The following subjects were excluded in the study

i. Male subject with excessive facial hair, which obscures some of thefaciallandmarks.
ii. Any particpant who wishes to decline his/ her informed consent.
iii. Subjects with cranio-facial anomalies.

3.3 ETHICAL APPROVAL AND INFORMED CONSENT

Ethical approval were sought from Ethical Committee of Ahmadu Bello University and Kano State Hospital Management Board. Informed consent was sought from the participants and persons whose photographs appear in the study (Appendix I and II).

3.4 STUDY DESIGN

The study was carried out in three phases (Figure 3.2);

i. Phase I: This involved field data collection; this includes collection of biodata and body anthropometry (height and weight) using questionnaire, this was followed by capturing of thefrontal and lateral profile of the face using adigital camera (Samsung, ES90) this was followed by capturing of thumbprints using alive scanner (digitalpersona). The fingerprints and facial images were saved for each individual with similar codes.

ii. Phase II: This involved the reading of the study variables from images of faces and fingerprints captured in the field. The questionnaire and images codes were matched before reading and recording of the image variables.

iii. Phase III: The phase involved transfer of all the information from questionnaires and images into Microsoft excel for subsequent use during analyses.

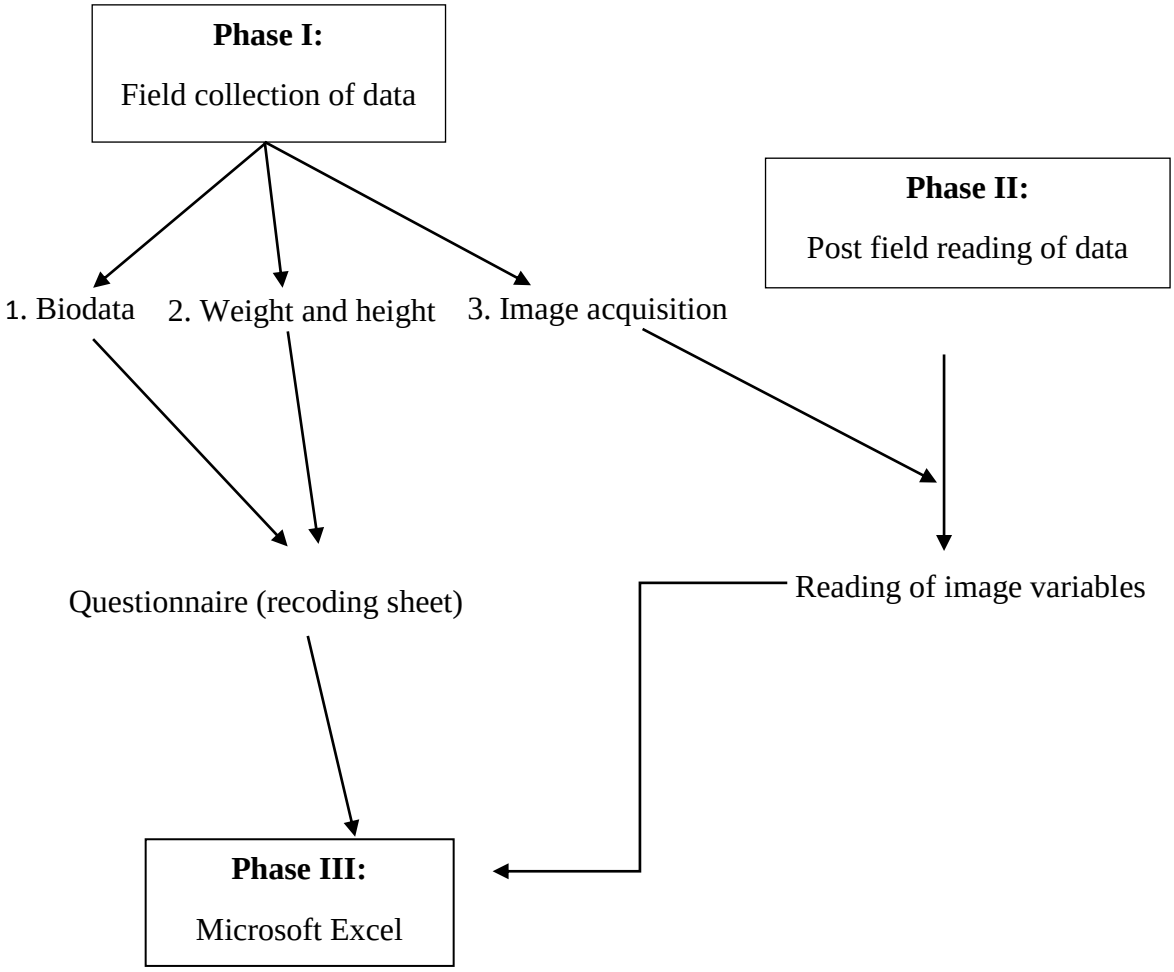


Figure 3. 2: A brief description of the study design

3.5 METHODOLOGY

3.5.1 Collection of Biodata

A brief questionnaire was completed for all individuals that included questionnaire code, date of birth, thelocation of birth, tribes of parents and grandparents (Appendix III).

3.5.2 Height, Weight, and Body Mass Index

3.5.2.1Height

The participants were asked to remove their shoes and any headwear or hair ornaments. They were then asked to stand on the stadiometer (RGZ, 160) with their back against the measuring rod, with feet slightly apart, the trunk balanced over the waist, knees straight, arms and shoulders relaxed. The head stop was then slid down until it touched the top of the head and the head was maintained in Frankfort plane. The subject was then asked to take a deep breath so as to straighten the spine to give a consistent measurement. The measurement was read from the display to the nearest 0.1 cm.

3.5.2.2 Weight

The weight was measured in kilograms using a digital weighing scale while the participant was in light clothes. The participant was asked to remove any heavy objects and take off his or her shoes and all accessories and the scale was then put on a perfectly flat surface with no obstructions. The participant was then asked to stand on the scale and remain still until the readings appear. The weight in kilogram was then read to the nearest decimal place.

3.5.2.3 Body mass index

The BMI wascalculated by dividing the weight in kilograms by the square of the height in metersand the result expressed in kg/m^2.

2.5.3 Fingerprint Collection and Analyses

3.5.3.1 Image capturing

A direct sensing fingerprints capturing method (Jain *et al.*, 2007) was used. A software (Printnalyser version 1) was designed using Microsoft visual basic (version 6.0) programming language in order to save each thumbprint with the participant'sbiodata in two different sizes (original and enlarge size).

The participant was asked to clean his/her thumb to remove any dirt that may be associated with the skin ridges. The thumb was then placed on the fingerprint sensor, digitalpersona (Plate I). After capturing a thumbprint, the type of finger (thumb), sex (male or female), side of the finger (left or right) and unique code of the (questionnaire code) of the participants were saved with each thumbprint. The typical name of each saved thumbprint carried the finger side, sex, unique code and size [for example thumb left female (Kn204) original size].

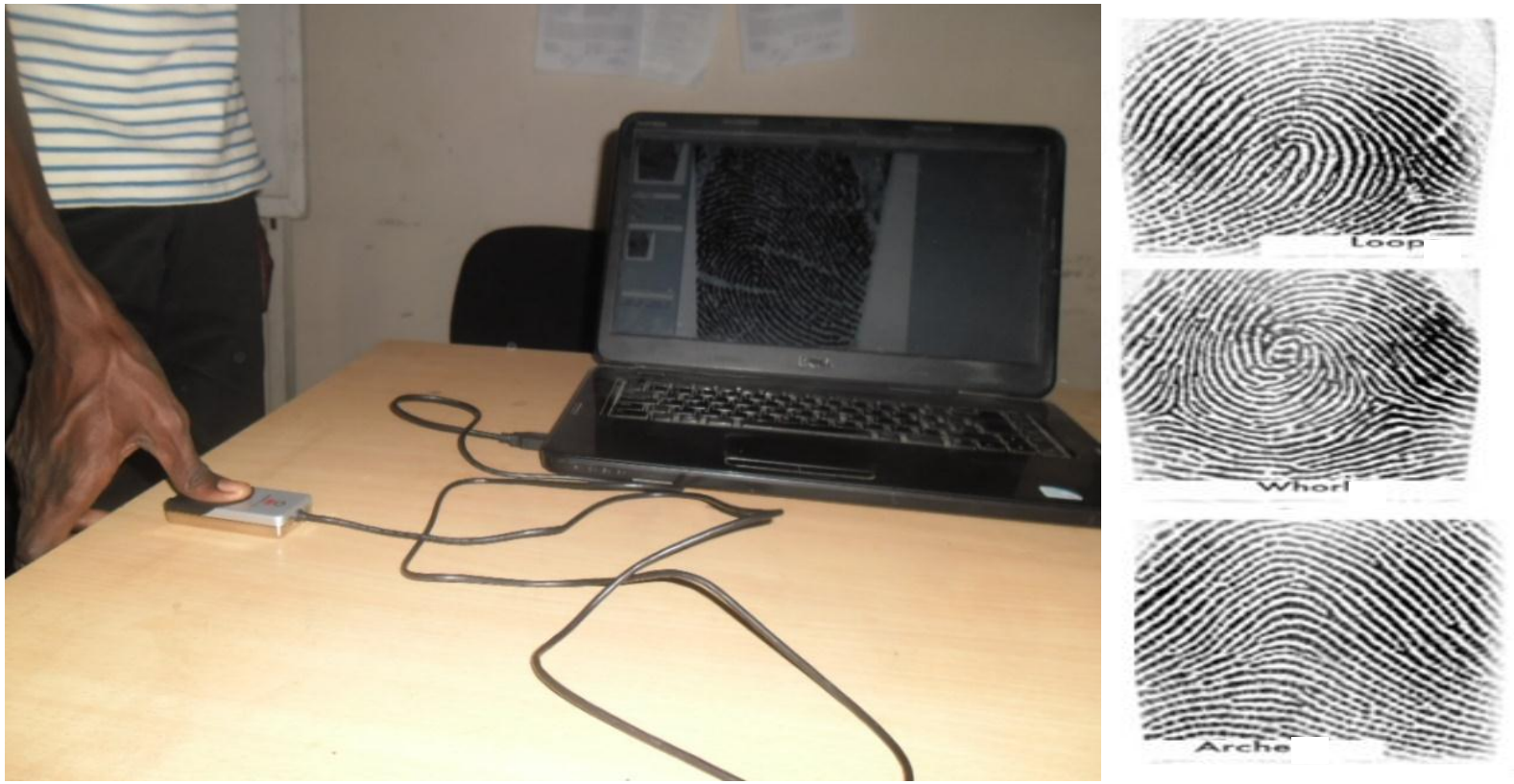
For each thumbprint, two versions were captured, the original size image (used for scaling) and amplified image (at a ratio of 7.74). The images were saved in jpeg format for variables reading in apersonal computer. The amplified thumbprints images were used for the analyses of the thumbprint profile. For the purpose of ensuring real size measurements, an ink method was used to collect the thumbprints of randomly selected participants. The thumbs were cleaned with tissue paper and freed from dirt. The subjects were made to roll the tip of their thumb across the surface of an already made ink-stained pad, ensuring that the ink covered the pattern area. The thumb was then transferred to a white paper to obtain the thumbprint (Oladipo and Akanigha, 2005). The value obtained from direct anthropometry was used for maintaining real size measurements.

3.5.3.2 Analyses

After saving each captured fingerprints in the computer, fingerprints to be analyzed were copied into working folder, a folder of which the contents can be imported into the software for analyses. The following fingerprint features were analyzed.

3.5.3.2.1 Pattern classification

The fingerprints were classified into any of the three basic patterns (Plate I), namely: Arch: a pattern where the ridges start from one side of the finger, rise in the centre forming an arc and then exit the side of the finger. Loop: a pattern where the ridge start from one side of a finger, form curves and exit from the same side. Whorl: a pattern where the ridges form circularly around a central point on the finger (Langerberg, 2005; Adebisi, 2009b).

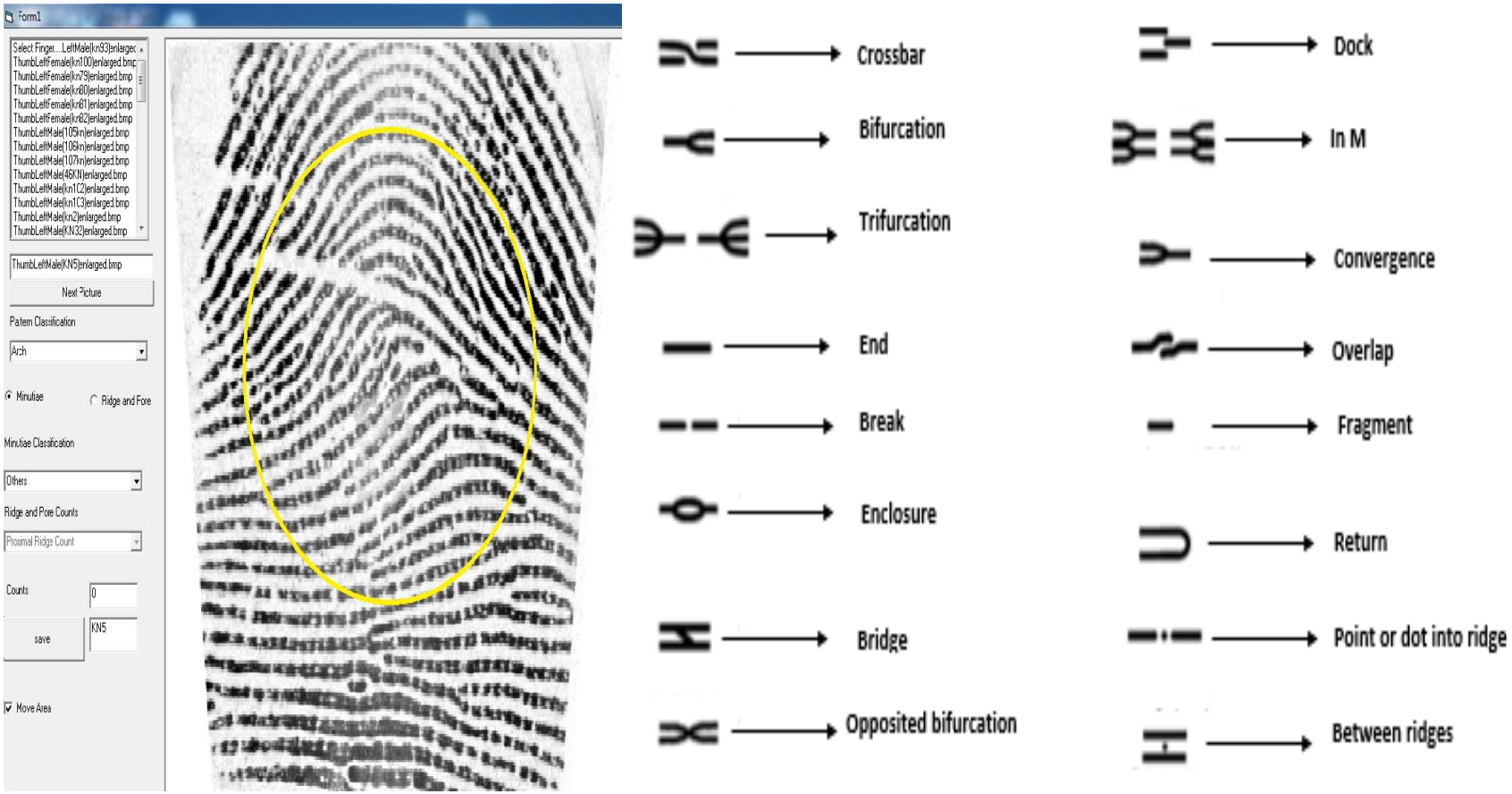


PlateI: Capturing and pattern types of thumbprint

3.5.3.2.2 Ridge minutiae types and counts

The minutiae count, designed according to the method described by Okajima (1970) were done using magnified images of the thumbprint. The thumbprints were divided into two areas (center and periphery) by a circle with a diameter covering about 18 ridges. Only minutiae within the circle were counted (Plate II).

The minutiae were classified into any of the following types (Plate II); ridge ending; a termination of a ridge; bifurcation, when the minutiae form ridges to the right; convergence, when the minutiae form ridges to the left; trifurcation (convergence and bifurcation), when the minutiae form three ridges; fragment (big or small), short ridge with length equal or less ten times its width. point or dot, one ridge unit which contains only one sweat gland pore; break, two ends of ridge very near and opposite; enclosure (big or small), where the ridge path divides and then comes together again; overlap, where two ridge ends meet and overlap on a bias; cross-bar, ridge that separates from its direction crossing between two others; bridge or crossover, where a short ridge crosses from one ridge to join the next; opposite bifurcations, two ridges that join at one point; Y or M (convergence and bifurcation), when two bifurcations develop next to each other on the same ridge a unique formation; dock, crest end that enters between two other end ridges; and return, the turning around of a ridge without being part of the nucleus (Champod,, 1996; Gutie´rrez-Redomero *et al.*, 2007).



PlateII: A thumbprint divided into two areas (inside and outside the circle) for determination of different types of minutiae

3.5.3.2.3 Ridge density anthropometry

According to the method described by Acree (1999), ridge density (RD) (i.e., number of ridges in a given space) was measured from the count of ridges found diagonally within a 5 mm x 5 mm square on the fingertip surface of an area located on the radial side of the distal region of each finger (Plate III). The number of ridge count in two additional areas were also considered one on the ulnar side of the distal region and the other in the proximal region, following the methodology proposed by Gutiérrez-Redomero *et al.* (2008).

To locate the three count areas, the thumbprint was divided into two sections by avertical line that passes through the center of the ridges. The 5 mm^2 x 5 mm^2 radial and ulna areas were defined by the side of the vertical line; whereas for theproximal area, the vertical line transversed the 5 mm^2 x 5 mm^2. In order to facilitate counting, the ridge count was carried out using the magnified image (Gutie´rrez-Redomero *et al.*, 2012; Krishan *et al.*, 2012; Gutiérrez-Redomero *et al.*, 2013).

3.5.3.2.4 Ridge thickness anthropometry

Ridge thickness (RT): this was measured as a distance from the centre of one furrow across the ridge to the centre of the next furrow. (Kamp *et al.*, 1999; Králík, and Novotný, 2003). Regions of interest for the ridge thickness were within the 5 mm x 5 mm square on radial and ulnar sides of the distal region of each finger and proximal region as proposed in fingerprint ridge density counts (Gutie´rrez-Redomero *et al.*, 2012; Krishan *et al.*, 2012; Mundorff *et al*., 2014).

The indirect method of the ridge thickness measurement was used. This involved acount of the ridges along the diagonal line of 7.07 mm length. The length of the line 7.07 mm was divided by a number of the ridges in a given area. This gaves the estimated of ridge thickness of the thumbprint in three different areas (Plate III).

3.5.3.2.5 Ridge pores anthropometry

From the captured thumbprint, the regions of interest for pore counting were within a 5 mm x 5 mm square areas in theproximal region as proposed in fingerprint ridge density counts (Gutie´rrez-Redomero *et al.*, 2012; Krishan *et al.*, 2012). For a pore to be counted, complete or more than half of it must fall within the squares (Plate III).

Figure 3.3 showed the summarised flow chart of fingerprint profile analyses using print analyses software. The profile analysed include, thumbprint pattern, ridge count, ridge trhickness (indirect) and ridge pores count.

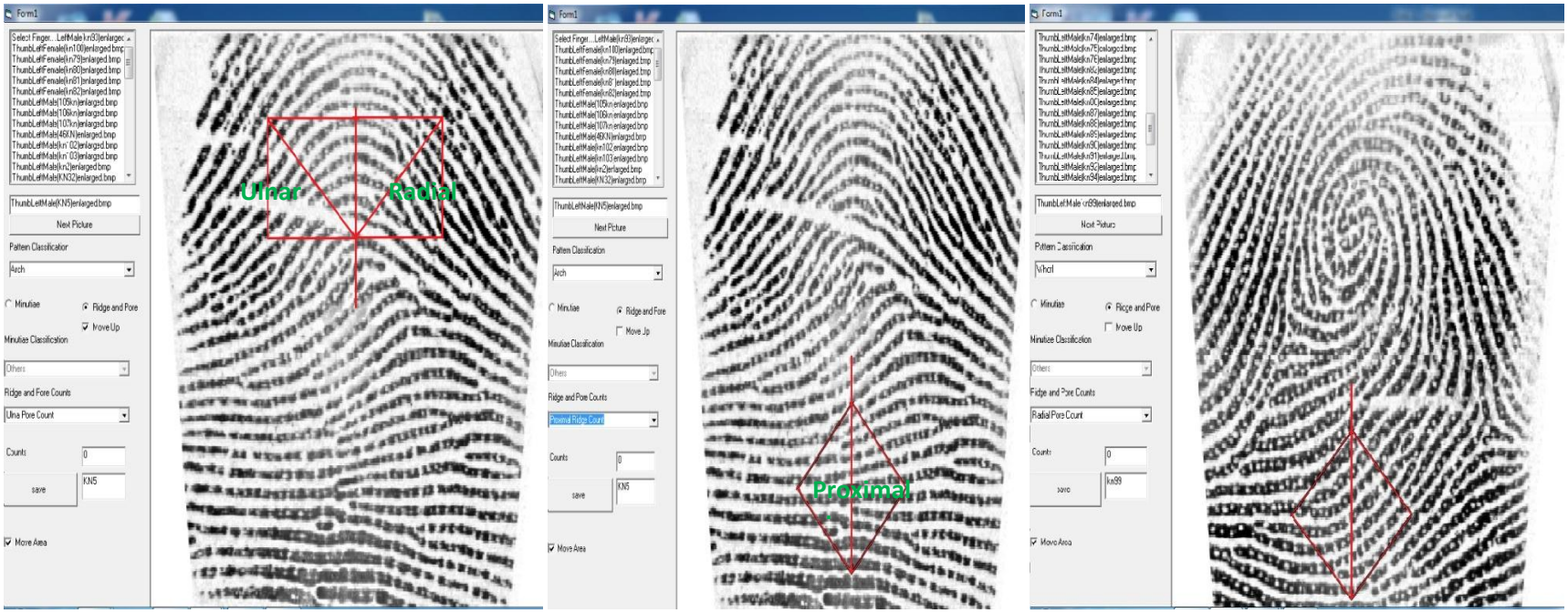


Plate III: Radial, ulnar and proximal area of fingerprint for ridge density, thickness and pores determination

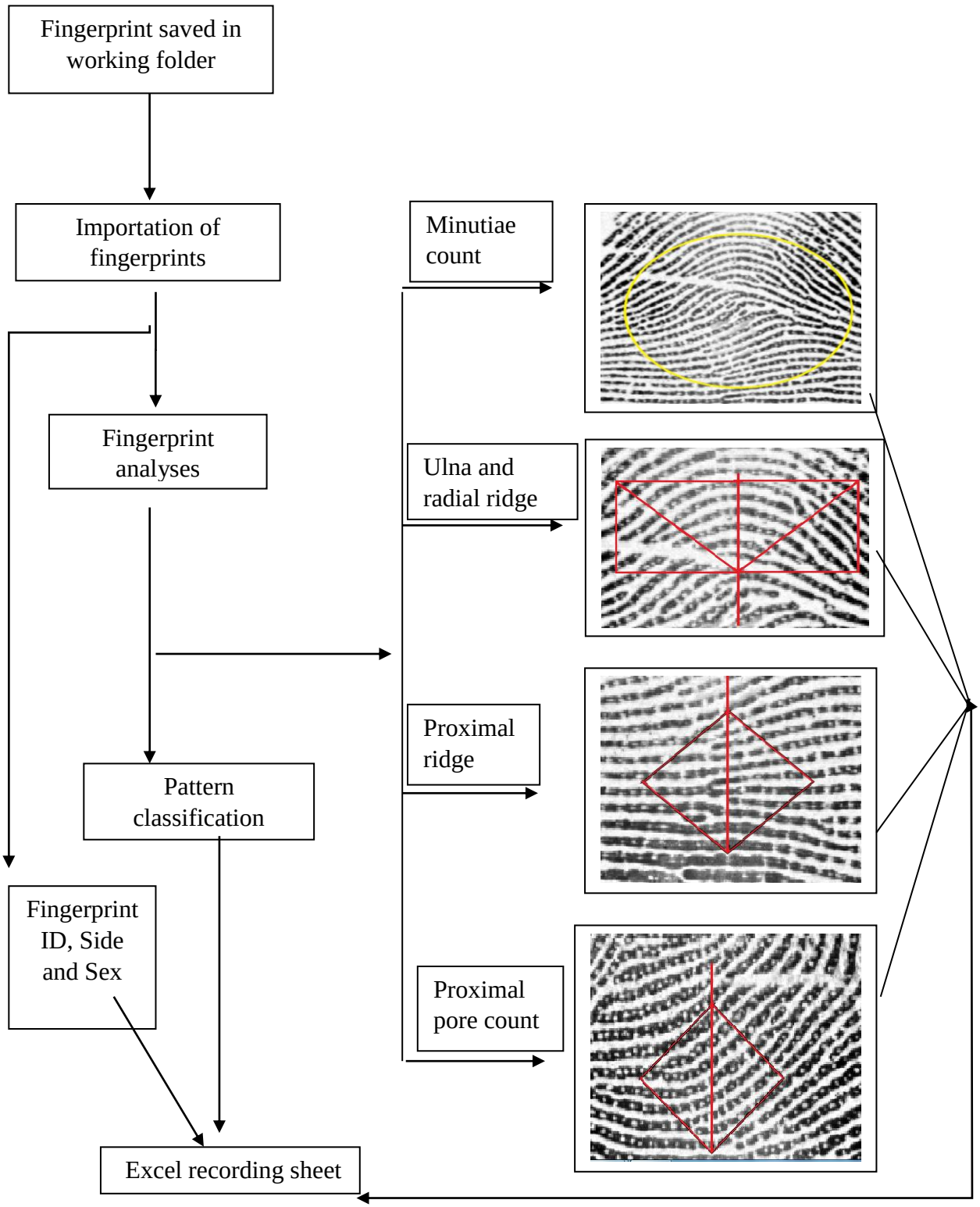


Figure 3.3: Thumbprint profile analyses flow chart

3.5.4 Face Capturing and Analyses

3.5.4.1 Facial image capturing (frontal and lateral view)

To obtain the photographs (frontal and lateral), individuals were asked to sit and, look directly at the camera in front of them (Moorrees, 1994) keeping an upright and normal posture, with both arms free along the body. This position correspond to the Broca's Natural Head Position (Ferrario *et al.,* 1993). Behind the subjects was placed a white screen to standardise the background (Plate IV).The camera was placed on a tripod stand (Plate IV) (WT3570, China) to standardise the distance (100 cm) between it and the subject as well as adjust the camera according to sitting height of the subject. In addition, the tripod helped to avoid undesirable movements of operator and camera while taking photographs (Morosini *et al.,* 2012). Before capturing the face, the operator ensured that glasses (if worn) had been removed, the patient's forehead, neck, and ears were clearly visible during the process (Reddy *et al*., 2011).After the images were captured, those images were downloaded to apersonal computer and stored in jpeg format for processing and analyses.

For measurement error analyses, a direct facial anthropometry was adopted (Farkas, 1994). This involved asking the participant to sit with his head in natural head position. A digital vernier caliper (Neiko 01407A, China) was then used to measure the facial linear dimension whereas, a hinge was used to measure the frontal and lateral angles of face indirectly and goniometer was used for the measurement of the angles. This helped in the determination of the factor to be used for real size measurements of the photographs. The factor was 0.45 which was obtained by dividing actual size measurement with actual pixel of the image measurement.



Plate IV: Photographic set up for facial image capturing

3.5.4.2 Facial analyses

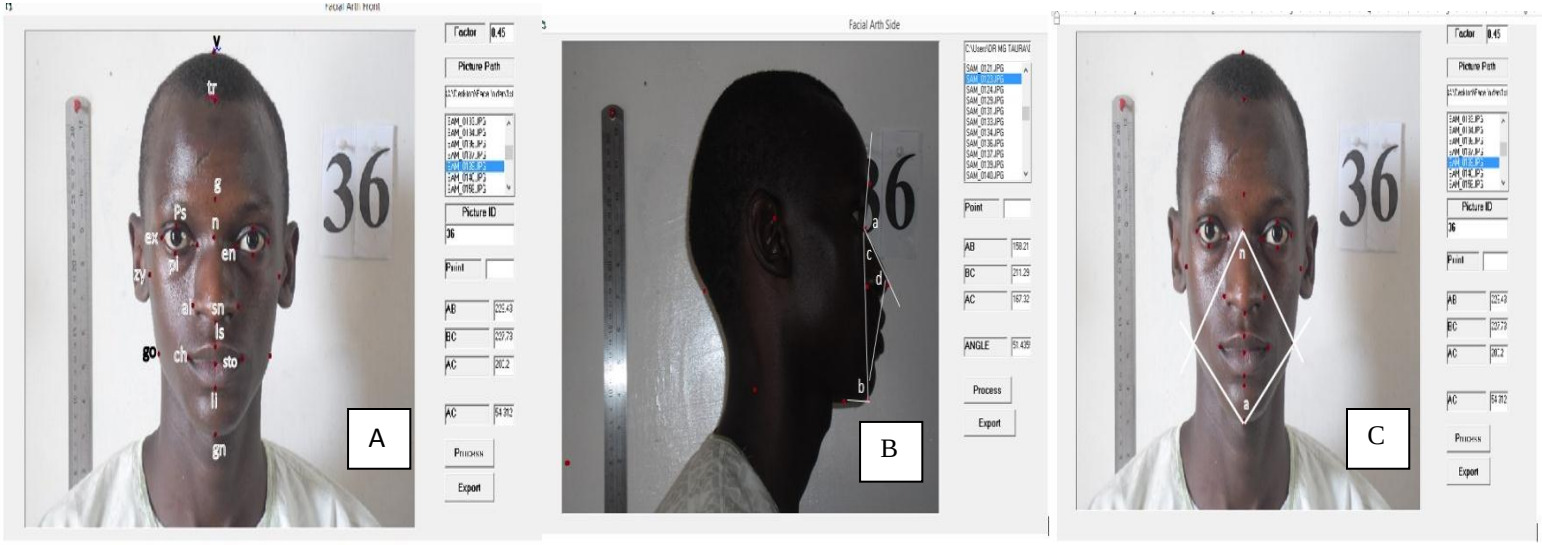
The capture facial images were imported into a software, bio-analyser. Each image contained specific code. The images were arranged in analternate of thefrontal and lateral image. The facial image was diplayed in picture area. The facial land-marks were placed in the respective positions (Plate V). The facial dimention and angles were measured automatically (Plate V) in a fraction of a minute. The entire measurements were exported to excel. Other important features of the bio-analyser include, picture ID bar, which was used to input the specific ID of the participant for identity. Land-mark identification bar, this helped in knowing each specific landmark, by clicking on the land-marks, the name of the landmark appeared. Hence, this was used to ensure correct placement of the landmarks. Factor bar, which helped in ensuring the real size measurements using appropriate factor.

3.5.4.3 Facial landmark identification

Table 3.1 showed anatomical landmarks recognised for both frontal and lateral facial views (Farkas, 1994; Porter and Olson, 2001; Gibellia *et al.*, 2012).

Table 3.1: Anatomical landmarks used for linear facial measurements (Farkas, 1994; Porter and Olson, 2001; Gibellia et al., 2012).

S/N	Landmarks	Abbr	Anatomical description
1	Alar	Al	This is the most lateral point of the nasal wings.
2	Endocanthion	En	This is the inner corner of the eye fissure at the meeting points of eyelids.
3	Exocanthion	Ex	It is the outer corner of the eye fissure where the eyelids meet.
4	Glabella	G	This is amost prominent point in the median sagittal plane between the supraorbital ridges.
5	Gnathion	Gn	It is the lowest point on the lower border of the chin, in the midline.
6	Gonion	Go	the midpoint of the mandibular angle
7	Labiale inferius	Li	the midpoint of the lower vermilion line
8	Labiale superius	Ls	the midpoint of the upper vermilion line
9	Nasion	N	This is the midpoint of the nasofrontal suture.
10	Palpebrale inferius,	Pi	lower eyelid center
11	Palpebrale superius	Ps	upper eyelid center
12	Stomium	Sto	Mid-point of the mouth orifices
13	Subnasale	Sn	It is the junction between the lower border of the nasal septum and the cutaneous portion of the upper lip, in the midline.
14	Trachion	Tr	The midpoint of the hairline at the top of forehead
15	Vertex	V	This is the highest point on the head with the head in the Frankfort horizontal plane.
16	Zygion	Zy	This is the most lateral point on the zygomatic arch.



PlateV: A; Landmarks for measurement of facial dimensions, B; Lateral facial angles, C; frontal facial angles

3.5.4.4 Facial linear dimension measurement

The facial linear dimensions were obtained as thedistance between one anatomical landmark and another (Table 3.2).

3.5.4.4 Facial angles (lateral and frontal)

From the lateral photographs, four lateral angles (Oghenemavwe *et al.*, 2010; Reddy *et al.*, 2011) were recorded as follows; Naso-frontal angle: it was formed by drawing a line tangent to the glabella through the nasion that intersect a line drawn a tangent to nasal dorsum. Mento-cervical angle: it was formed drawing a vertical line tangent to the forehead passing through the glabella and pogonion and second line intersecting tangent to the chin of the mention. Naso-facial angle: it was formed by drawing a vertical line tangent to the forehead at the glabella and tangent to the chin at pogonion so that a line drawn along the nasal dorsum intersects it. Naso-mental angle: it was formed by a line drawn through the nasal dorsum intersecting a line drawn from the nasal tip to soft tissue chin pogonion. With respect to frontal photograph, two frontal facial angles (Morosini *et al.*, 2012) were considered. Nasion angle: formed by lines drawn by the intersection of nasion to gonion and nasion to gonion lines. Facial aperture modified angle formed by theintersection of right and left lines from ex to go landmarks (Table 3.1 and Plate V).

Figure 3.4 showed the summarised flow chart of facial profile analyses using print analyses software. The profile analysed include, linear distances and angles (frontal and lateral).

Table 3.2: Linear facial dimensions and ratio with their corresponding landmarks (Farkas, 1994; Porter and Olson, 2001)

	Facial linear distances	**Landmarks**		**Facial ratios**	**Description**
1	Special head height	v-en	1	UFW/LFW	Upper facial width to lower facial width
2	Special face height	en-gn	2	UFW/UFH	Upper facial width to upper facial height
3	Forehead height II	tr-n	3	LFH/FH	Lower face to face height
4	Nose length	n-sn	4	UFW/LFH	Face width to the lower face height
5	Lower face height	sn-gn			
6	Height of calva	v-tr			
7	Forehead height I	tr-g			
8	Special upper face height I	g-sn			
9	Interocular distance	en-en			
10	Nasal width	al-al			
11	Upper facial width	zy- zy			
12	Philtrum length	sn- ls			
13	Lower facial width	go- go			
14	Upper lip length	sn- sto			
15	Height of lower third of the face	sto- gn			
16	Mouth height	ls- li			
17	Mouth width	ch-ch			
18	Upper vermilion width	ls-sto			
19	Lower vermilion width	sto-li			
20	Orbital width	ps- pi			
21	Orbital length	ex-en			
22	Zygon to vertex	zy- v			
23	Zygon to gnathion	zy- gn			

3.5.4.5 Facial proportion

Table3.3 showed seven neoclassical canon facial proportion and their variations. The vertical canon considerd were two, three and four sections neoclassical facial canon. The horizontal canons, orbitonasal, orbital, naso-oral and naso-facial were determined (Farkas, 1994).

Table 3.3: Seven neoclassical canon facial proportion and their variations (Farkas, 1994)

SN	Classes	Description	SN	Classes	Description
1	Class I[1] and its variation	Special head height = special face height Special head height > special face height Special head height < special face height	4	Class V[5] and its variation	Interocular distance = Nasal width Interocular distance > Nasal width Interocular distance < Nasal width
2	Class II[2] and its variation	Forehead height II = upper facial height = lower facial height Upper facial height < lower facial height Forehead height II > lower facial height Forehead height II < lower facial height Forehead height II > lower facial height	5	Class VI[6] and its variation	Interocular distance = Orbital length Interocular distance > Orbital length Interocular distance < Orbital length
3	Class III[3] and its variation	Height of calva = forehead height I = special upper height I = lower facial height Height of calva < forehead height I Height of calva < special upper height I Height of calva < lower facial height Height of calva > forehead height I Forehead height I > special upper height I Forehead height I < lower facial height Special upper height I < lower facial height	6	Class VII[7] and its variation	Mouth width = 1.5 (Nasal width) Mouth width > 1.5 (Nasal width) Mouth width < 1.5 (Nasal width)
			7	Class VIII[8] and its variation	Nasal width = 0.25 (Upper facial width) Nasal width > 0.25 (Upper facial width) Nasal width < 0.25 (Upper facial width)

1,2,3, two, three and four sections facial profile canon respectively. 5,6,7,8, orbitonasal, orbital, naso-oral, nasofacial proportion canon respectively.

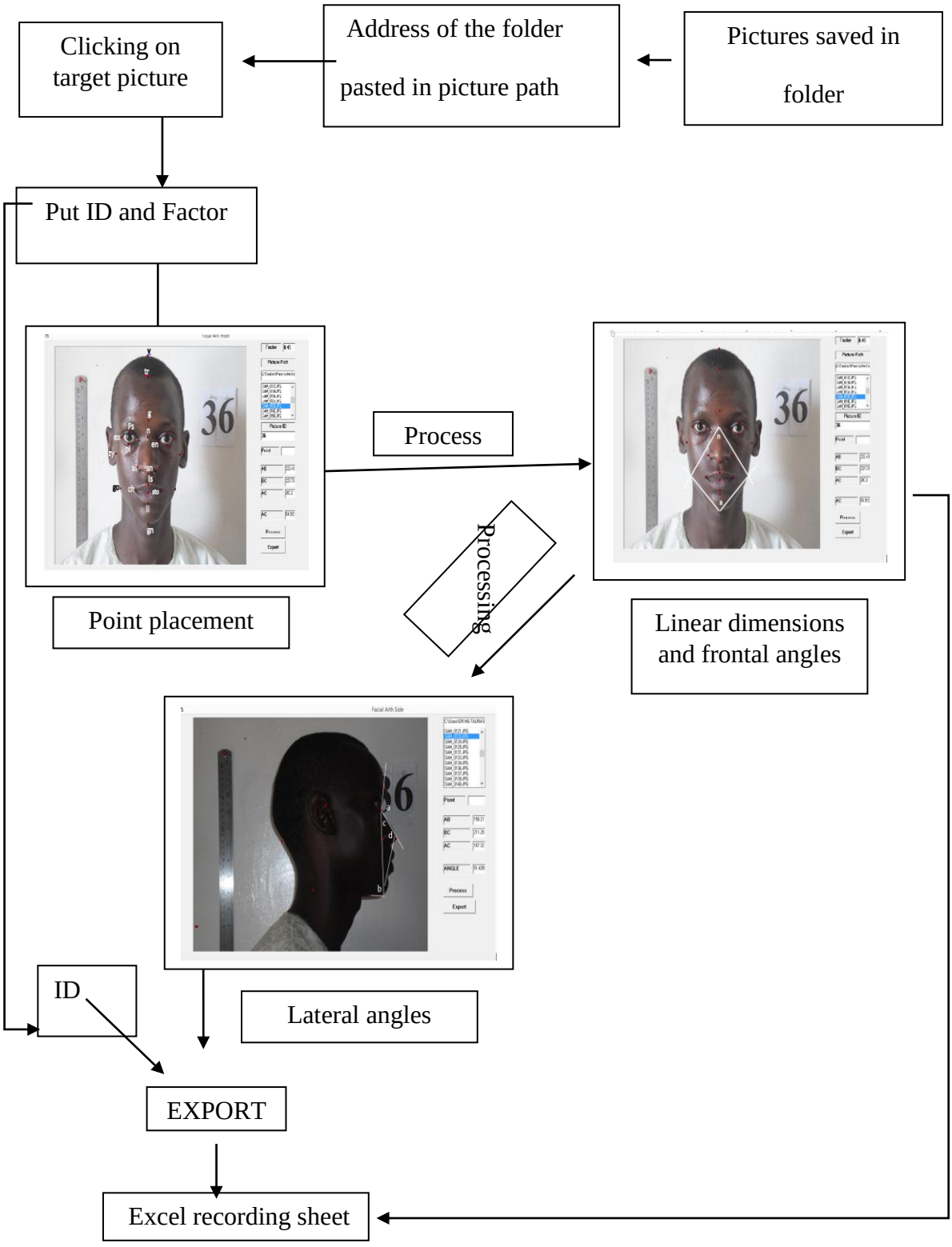


Figure 3.4: Flow chart of facial profile analyses

3.6ASSESSMENT OF ASYMMETRY

3.6.1 Test for Fluctuating Asymmetry (FA)

3.6.1.1 Calculation of asymmetry values

Three indices of asymmetry, differences between left (L) and right (R) used include; signed asymmetry (SA), absolute asymmetry (AA) and composite asymmetry (CA). These were determined by the following formulae; SA = R-L, AA = $\sqrt{(R-L)^2}$, CA = $\sum\sqrt{(R-L)^2}/n$, where n is the sample size.

3.6.1.2 Test of asymmetry

The existence of directional asymmetry was detected by subjecting the mean value of signed asymmetry to one sample t - test (Manning, 1995; Palmer and Strobeck, 2003). An asymmetry was directional, if themean value of signed symmetry differs significantly from zero, otherwise, it was considered as fluctuating asymmetry.

3.6.1.3 Test of normality

To determine the departures from normality, skewness and kurtosis for signed asymmetry were checked. When a trait is significantly skewed or exhibit kurtosis significantly ($P < 0.05$), the trait was not considered as agood indicator of fluctuating asymmetry (Palmer and Strobeck, 2003).

3.6.1.4 Test of repeatability of asymmetry

Two-way mixed analysis of variance (split plot ANOVA) was used for separation of measurement error from the analysis of left-right asymmetry. With ‘measurement’ as thedependent variable, ‘individual’ as the fixed factor, and ‘side’ and the ‘individualside’interaction as random factors (Palmer and Strobeck, 1986; Palmer, 1994). In this test, interaction (individualside) was used to estimate fluctuating asymmetry and statistical significance of the FA estimate was determined by the F-statistics. It was suggested that in FA study, a repeated measurements must be taken from each individual (Palmer and Strobeck, 2003). In this study, the photographs/images of 30 participants were measured twice in order to determine measurement error since it is not feasible to measure the entire participants twice. A trait is not considered as agood indicator of fluctuating asymmetry if asymmetry variance (differences between left and right sides measurement) is not significantly greater than measurement error variance (differences between first and second measurements).

3.6.1.5 Test of size dependency

The symmetry of an individual trait may vary as the size of the trait varies (Palmer and Strobeck, 2003). Spearman’s rank correlation coefficient was used to quantify the relationship between unsigned asymmetry (absolute asymmetry) and mean trait size (mean value of a given variable) for all traits. A trait was considered as agood indicator of fluctuating asymmetry if there is no correlation between unsignedasymmetryand mean trait size ($P > 0.05$). Tthere is no indication of size dependency for the trait.

3.7 ASSESMENT OF MEASUREMENT ERROR

3.7.1 Precision of Measurements

To quantify precision (definedasthedifferenceinvaluesobtainedwhenmeasuringthe same object repeatedly. It is the closeness of the two repeated measurements), two sets of measurements taken with each method were compared using technical error of measurement (TEM). This allowed assessment of random error. The TEM (also called the ‘‘method error statistic’’) is a standard-deviation−like estimate of error magnitude expressed in the original units of measurement. It can be used to generate both Intra and inter-observer precision estimates. When there are two measurements involved, the formula for TEM (Aldridge *et al*., 2005) is as follows:

Absolute TEM = $\sqrt{\sum}di^2/2n$

Where: Σd^2 = summation of deviations (The difference between the 1st and 2nd measurements) raised to the second power;

n = number of volunteers measured

i = the number of deviations

The absolute TEM was expressed as percentages as follows;

Relative TEM = $\frac{\text{Absolute TEM}}{\text{VAV}} \times 100$

Where; VAV = Variable average value; this is the arithmetic mean of the mean between both measurements obtained (1st and 2nd measurements) of each volunteer for the same variable. This procedure was performed for each one of the n participants and then averages obtained were summed up and divided by n (total of a number of participants) (Perini *et al.*, 2005).

The percentage scores were divided into five precision categories: scores less than 1% was deemed ‘‘excellent,’’ scores ranging from 1% to 3.9% were deemed ‘‘very good,’’ scores ranging from 4% to 6.9% were deemed ‘‘good,’’ scores ranging from 7% to 9.9% were deemed ‘‘moderate,’’ and scores exceeding 10% were deemed ‘‘poor (Weinberg *et al.*, 2004).’’

3.7.2 Strength of Measurements (r)

The r was computed to demonstrate the strength of the relationship (similarities) between two measurements. Intraclass correlation (ICC) was used for this purpose. The values for the reliability coefficient ranged from 0 to 1, where ICC < 0 indicated “no reliability”, ≥ 0 but <0.2 “slight reliability”, 0.2 to < 0.4 “fair reliability”, 0.4 to < 0.6 “moderate reliability”, 0.6 to < 0.8 “substantial reliability”, and 1 “almost perfect reliability”(Shrout and Fleiss, 1979). The interval between two measurements was at least one week and 30 randomly selected records were used for this evaluation.

3.7.3 Systematic Error of Measurements

To determine thesystematic error in the minutiae counting, the Student’s paired t - test was performed to compare the means of the first and second counting. This allowed assessment of systematic error (bias error). This was considered as asubstitute of method error since in minutiae count there is always a possibility of zero counts (absent of particular type of minutiae).

3.8 DATA ANALYSES

The quantitative and qualitative data were expressed as mean ± SD and frequency/percentages respectively. Chi-square/ Fisher's exact test was used to test theassociation between variables. Independent sample t - test was used to test for sex differences in the variables.

Step-wise binary logistic regression was applied to obtain a predictive equation (BLR model) that discriminates the sex of the individual. In this model, the cut-off value was 0.5 and hence if the predicted value was equal to or more than 0.5 it was consideredas male and if less than 0.5 (or negative value) it was considered to be female. Predicted probabilities of BLR were analysed using receiver operating characteristic (ROC) curve. The ROC curve is a strong indicator of the model's ability to distinguish two groups and the area under the curve was used to measure the strength of the equation. Area under curve less than 0.5, it indicate that observation was purely a matter of chance and a value close to 1 indicates that the equation strongly discriminate two groups.

Pearson's correlation analyses were used to determine the relationship between thumbprint profile and BMI with facial profiles. Step-wise multiple linear regression analysis was used to predict BMI from facial and thumbprint profiles. Statistical Package for Social Sciences (SPSS), version 20 (IBM Corporation, for Windows) statistical software was used for the statistical analysis. Values $P < 0.05$ are considered significant.

CHAPTER FOUR

4.0 RESULT

4.1 MEASUREMENT ERROR

The assessment of error in the variables used in the study showed that in unpaired linear facial dimension, special head height showed least method error (1.39%) and higher single measured intraclass correlation (ICC) of 0.98. The rest of the measurements were also within the acceptable level of method error and intraclass correlation. Similarly, the paired linear dimension, facial angles, and ridge density were within anacceptable level of error with theexception of nasomental angles which was greater than 10%. A systemic assessment of measurement error also showed that there are no significant differences (P> 0.05) between first and second minutiae counts of the thumbprints. Higher ICC was observed in bifurcation and least in fragment small.

4.2 SEXUAL DIMORPHISM AND DISCRIMINATION AMONG HAUSAS

4.2.1 Using Thumbprint Pattern

In the right thumbprint male have higher percentages of all the three types of thumbprint patterns (Table 4.1). In the left thumbprint, the exception was whorl pattern, where females have ahigher percentage (Table 4.2). However, the differences observed were not significant.

Table 4.1: Association of sex and patterns of right thumbprint

Fingerprint pattern	Male (%)	Female (%)	Total
Arch	10 (62.50)	6 (37.50)	16
Whorl	58 (53.7)	50 (46.30)	108
Loop	76 (50.30)	75 (49.70)	151
Total	144 (52.40)	131 (47.60)	275

$\chi 2 = 0.987$, DF= 2, P= 0.611

Table 4.2: Association of sex and patterns of left thumbprint

Fingerprint pattern	Male (%)	Female (%)	Total
Arch	11 (57.90)	8 (42.10)	19
Whorl	39 (43.80)	50 (56.20)	89
Loop	90 (82.30)	64 (71.70)	154
Total	140 (53.40)	122 (46.60)	262
$\chi 2 = 5.01$, DF= 2, P= 0.082			

4.2.2 Using Thumbprint Ridge Density, Thickness, and Pores

Figures 4.1 – 4.6 show the mean sexdifferences in thumbprint ridge density. It was observed that females have significantly higher ulna ridge (10.91 against 10.01) in the right thumb (Figure 4.2) and significantly ($P < 0.05$) lower proximal ridge density (9.76 against 9.17) in the left thumb (Figure 4.2). As shown in Figure 4.3, the right thumbprint ridge thickness showed a significantly ($P < 0.05$) higher ulna ridge thickness in male (0.7 versus 0.66). However, in radial ridge thickness, the female recorded significantly ($P < 0.05$) higher mean value (0.71 against 0.68). In the left thumbprint, the females have significantly higher ridge thickness in both radial areas (0.7 versus 0.67) and proximal area (0.79 versus 0.73) ridge thickness (Figure 4.4). Similarly, in the right thumbprint, proximal area pores showed a significant sexual dimorphism, with higher pore count in females (63 versus 55) (Figure 4.5), and such differences were absent in left thumbprints (Figure 4.6).

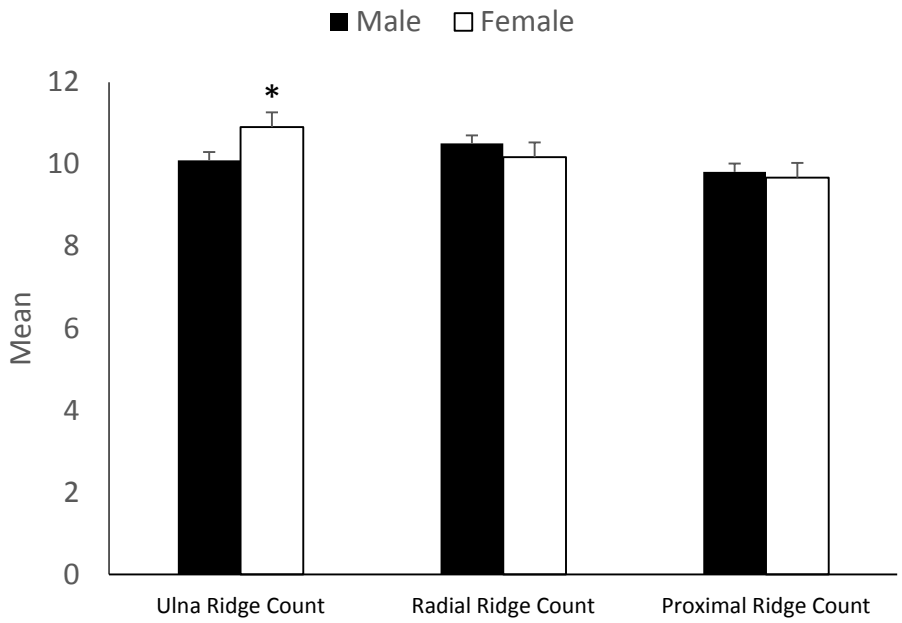


Figure 4.1: Sexual dimorphism in ridge density of the right thumbprint (*P< 0.05)

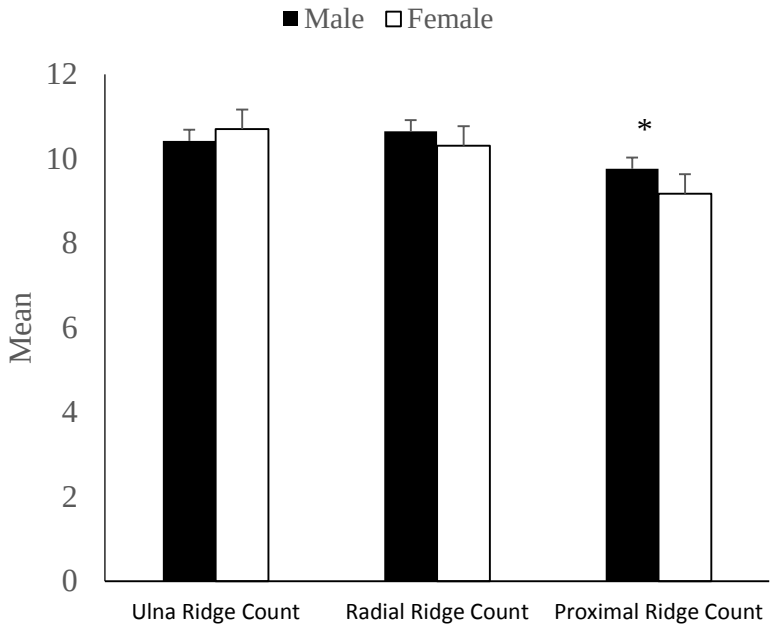


Figure 4.2: Sexual dimorphism in ridge density of the left thumbprint (*P< 0.05)

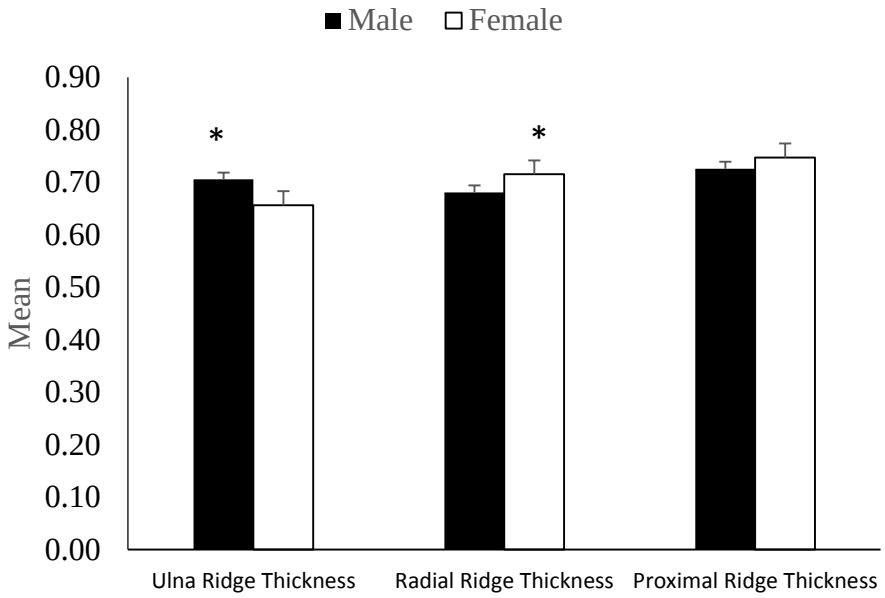


Figure 4.3: Sexual dimorphism in ridge thickness of right thumbprint (*P< 0.05)

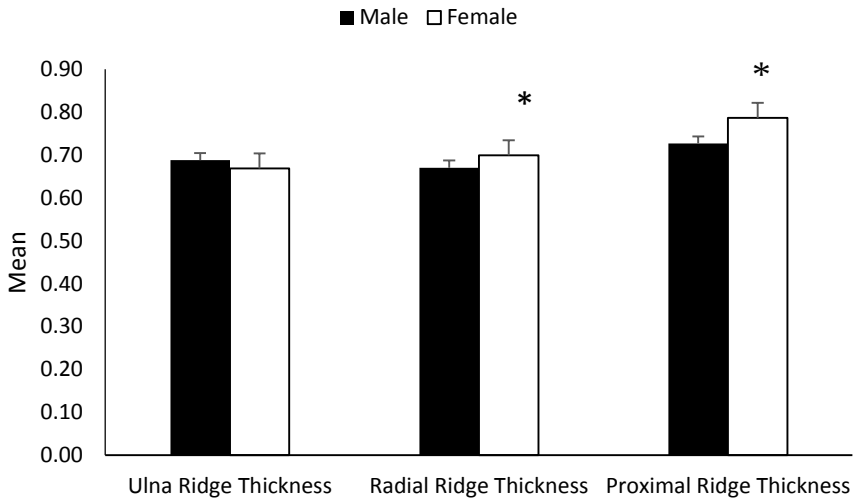


Figure 4.4: Sexual dimorphism in ridge thickness of left thumbprint (*P< 0.05)

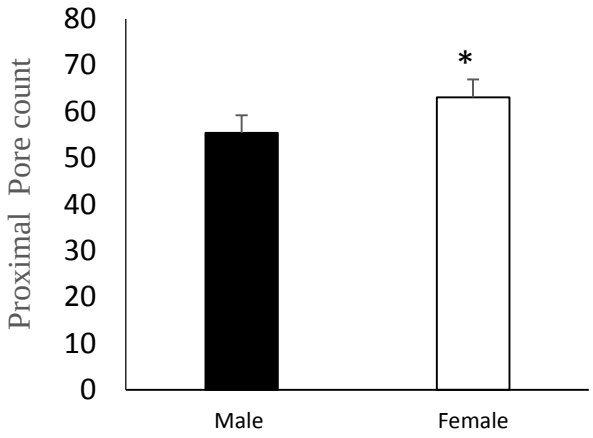


Figure 4.5: Sexual dimorphism in proximal ridge pore count of right thumbprint (*P< 0.05)

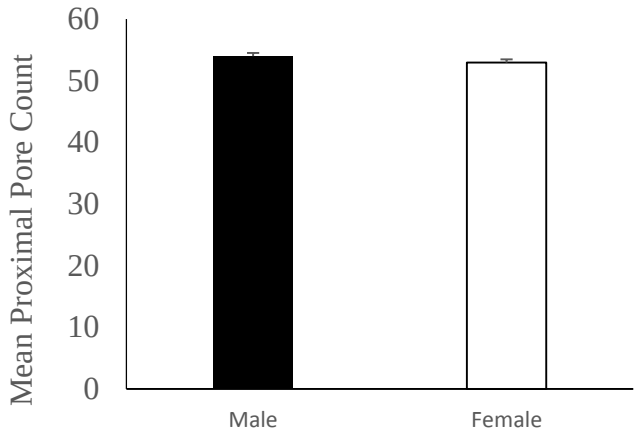


Figure 4.6: Sexual dimorphism in ridge proximal pore count of left thumbprint

Using sexually dimorphic trait of ridge density, step-wise (forward) binary logistic regression (BLR) showed that ulna ridge count was the single best variable to discriminate sex, with percentage accuracy of 63.4% and 8.5 – 11.5% contribution to the equation. This increased when the radial ridge thickness (second best variable) was added to the equation, to 68.5% and 12.3-16.5%. However, in the left thumbprints, the proximal ridge thickness discriminates sex with 62.4% accuracy and 5-7% contribution to the equation. The little increment was observed when the proximal ridge count was added to the equation (Table 4.3). The predicted probabilities of BLR for the variables that contributed best to the prediction were analysed using receiver operating characteristic (ROC) curve. It was observed that the ulna ridge count and proximal ridge thickness were the best predictors, with a higher area under the curve in the right and leftthumbprints, respectively (Figure 4.7).

Table 4.3: Generated equations for sex discrimination from thumbprint ridge density and thickness

Thumb	Steps	Equations (y=mx + c)	Accuracy (%)	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	$\chi 2$
Right	1	Sex = -0.419 (ulna ridge count) + 4.562	63.4	331.976	0.085	0.114	22.896*
	2	Sex = -0.503 (ulna ridge count) + -3.777 (radial ridge thickness) + 8.056 4.562	68.5	321.034	0.123	0.165	33.837*
Left	1	Sex = -4.159 (proximal ridge thickness) + 3.325	62.8	315.657	0.055	0.073	13.45*
	2	Sex = -1.36 (proximal ridge count) + -17.63 (proximal ridge thickness) + 24.232	62.8	311.265	0.072	0.096	17.843*

***P< 0.05**

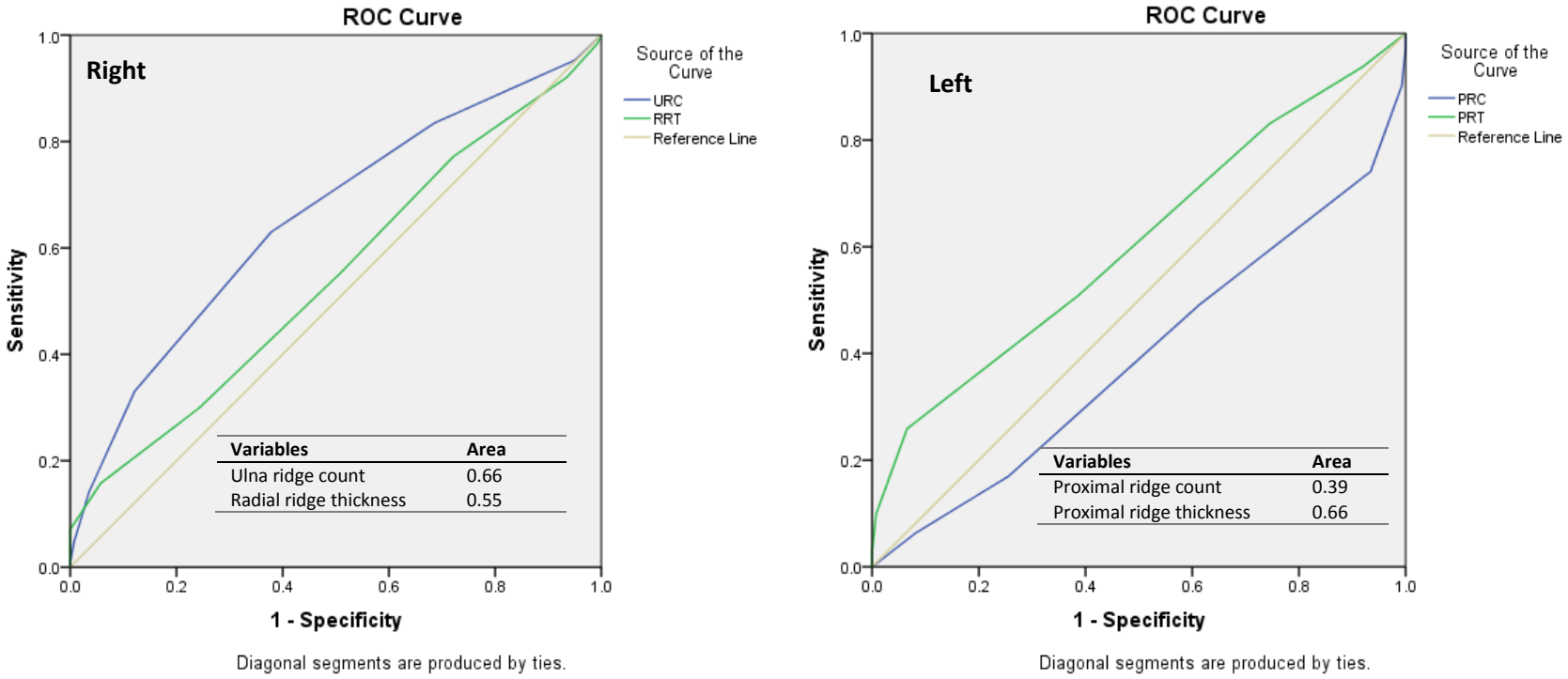


Figure 4.7: Receiver operating characteristics curve for determination of best model for sex discrimination using ridge count and thickness for the right thumbprint

4.2.2 Using thumbprint minutiae

For differences in the mean value of the right thumbprints minutiae, significant gender differences were observed only in ridge end, break, enclosure (big and small), and bridges and opposite bifurcation. The higher mean value was only in break and bridges in the female participants. In the left thumbprints, the significance was noticed only in abifurcation, cross bar, end, enclosure (small), convergence, return, point/dot between the ridges. Only return and convergence had higher mean value in the female (Table 4.4).

Table 4.4: Sex differences in the mean minutiae count of the thumbprint

	Right thumbprints			**Left thumbprints**		
	Male	Female		Male	Female	
Minutiae Type	Mean ± SD	Mean ± SD	t	Mean ± SD	Mean ± SD	t
Bifurcation	2.89 ± 2.17	3.12 ± 2.05	0.85	3.99 ± 2.94	3.10 ± 2.43	-2.53*
Crossbar	0.05 ± 0.22	0.08 ± 0.33	0.98	0.14 ± 0.48	0.03 ± 0.16	-2.30*
Trifurcation convergence	0.03 ± 0.18	0.04 ± 0.24	0.35	0.03 ± 0.18	0.02 ± 0.13	-0.70
Trifurcation bifurcation	0.01 ± 0.09	0.03 ± 0.16	1.03	0.06 ± 0.23	0.05 ± 0.25	-0.36
End	4.85 ± 3.59	3.19 ± 2.62	-4.13*	4.84 ± 3.48	2.66 ± 2.20	-5.67*
Break	0.55 ± 1.29	1.55 ± 2.15	4.40*	0.65 ± 1.26	0.69 ± 1.26	0.25
Enclosure (big)	1.39 ± 1.47	0.87 ± 1.11	-3.11*	1.10 ± 1.35	1.15 ± 1.16	0.29
Enclosure (small)	1.00 ± 1.60	0.68 ± 0.89	-1.95*	0.65 ± 1.02	0.32 ±0.90	-2.67*
Bridge	0.15 ± 0.40	0.47 ± 0.92	3.58*	0.23 ± 0.55	0.38 ±0.87	1.59
Opposite bifurcation	0.18 ± 0.44	0.04 ± 0.20	-3.09*	0.19 ± 0.43	0.19 ±0.44	0.01
Dock	0.06 ± 0.32	0.07 ± 0.25	0.26	0.02 ± 0.13	0.04 ±0.25	1.13
in "M" convergence	0.01 ± 0.01	0.08 ± 0.49	1.71	0.03 ±0.18	0.04 ±0.21	0.48
in "M" bifurcation	0.04 ± 0.20	0.02 ± 0.13	-1.09	0.08 ±0.27	0.04 ±0.21	-1.13
Convergence	1.48 ± 1.38	1.75 ± 1.62	1.43	1.17 ±1.34	1.98 ±2.00	3.70*
Overlap	0.28 ± 0.61	0.22 ± 0.45	-0.96	0.17 ±0.42	0.17 ±0.46	0.01
Fragment Big	0.35 ± 0.71	0.52 ± 1.22	1.33	0.33 ±0.73	0.55 ±1.09	1.87
Fragment Small	0.58 ± 1.34	0.53 ± 1.18	-0.29	0.51 ±1.07	0.34 ±1.15	-1.22
Return	0.02 ± 0.13	0.07 ± 0.34	1.55	0.00 ±0.00	0.09 ±0.32	3.14*
Point or dot into ridge	0.08 ± 0.37	0.18 ± 0.59	1.50	0.19 ±1.10	0.01 ±0.01	-1.87
Point or between ridges	2.48 ± 3.65	1.83 ± 3.06	-1.51	2.05 ±3.19	0.49 ±1.60	-4.69*

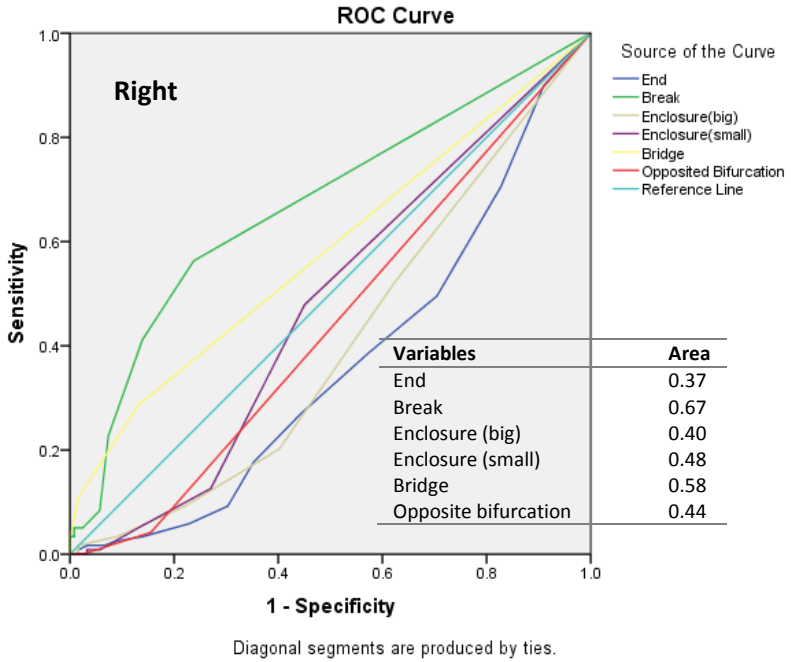
*P < 0.05, SD: standard diviation

Considering sexual dimorphic variable only, for discrimination of sex, it was shown that the best single sex discriminator in the minutiae of the right thumbprints was abreak with anaccuracy of 66.5% and 8-10% contribution to the prediction. However, when six minutiae types (break, end, enclosure big, enclosure small, bridges and opposite bifurcation) were added to the model, the accuracy was raise to 71.4% and 23-31% contribution to the prediction. The predicted probabilities of BLR for the variables that contributed best to the prediction showed that only break and bridges (Figure 4.8) were the best predictor with ahigher area under the curve. The left thumbprint minutiae showed that end minutiaewere the best with anaccuracy of 65.4% and 12-16% contribution to the prediction. However, when six minutiae types (end, bifurcation enclosure small, convergence, return and point/dot between the ridges) were added to the model, the accuracy raised to 75.6% and 32-43% contribution to the prediction (Table 4.5). The predicted probabilities of BLR for the variables that contributed best to the prediction showed that only return and convergence (Figure 4.8) were good predictors with anarea under the curve above 0.5.

Table 4.5: Generated equations for sex discrimination minutiae types of the thumbprint

	Steps	Equations (y=mx + c)	Accuracy (%)	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	$\chi 2$
Right	1	Sex = -0.406x (Break) - 0.399	66.4	313.835	0.08	0.107	20.22*
	2	Sex = 0.165 x (End) + (-0.374) (Break) - 0.26	67.6	300.761	0.129	0.172	33.29*
	3	Sex = 0.184 x (End) + (-0.316) Break + 0.355 (Enclosure big) - 0.74	66.8	290.695	0.165	0.22	43.37*
	4	Sex = 0.171 x (End) + (-0.342) Break + 0.358 (Enclosure big) + (-0.67 x Bridge) - 0.525	68.9	282.861	0.191	0.255	51.20*
	5	Sex = (0.169 x End) + (-0.344 x Break) + (0.316 x Enclosure big) + (-0.716 x Bridge) + (1.346 x Opposite bifurcation) - 0.59	70.5	274.911	0.218	0.29	59.15*
	6	Sex = (0.178 x End) + (-0.348 x Break) + (0.316 x Enclosure big) + (0.25 x Enclosure small) + (-0.687 x Bridge) + (1.352 x Opposite bifurcation) - 0.845	71.4	269.986	0.233	0.311	64.07*
Left	1	Sex = (0.274 x End) -0.878	65.4	293.723	0.121	0.161	30.05*
	2	Sex = (0.243 x End) + (0.283 x Point between ridges) -1.047	70.1	278.875	0.175	0.233	44.90*
	3	Sex = (0.188 x Bifurcation) + (0.257xEnd) + (0.312 x Point between ridges) -1.811	70.1	266.853	0.216	0.288	56.92*
	4	Sex = (0.201 x Bifurcation) + (0.231xEnd) + (-24.16x Return) + (0.559x Point between ridges) -1.792	73.5	244.137	0.288	0.385	79.6*
	5	Sex = (0.158 x Bifurcation) + (0.2281xEnd) + (-0.231 x convergence) +(-24.27x Return) + (0.54x Point between ridges) -1.256	74.4	238.325	0.306	0.408	85.45*
	6	Sex = (0.156 x Bifurcation) + (0.23 x End) + (0.479 x enclosure small) + (-0.282 x convergence) +(-23.91x Return) + (0.51 x Point between ridges) -1.377	75.6	230.848	0.328	0.437	92.93*

Cut value is 0.5 (negative value indicate female) *P < 0.05



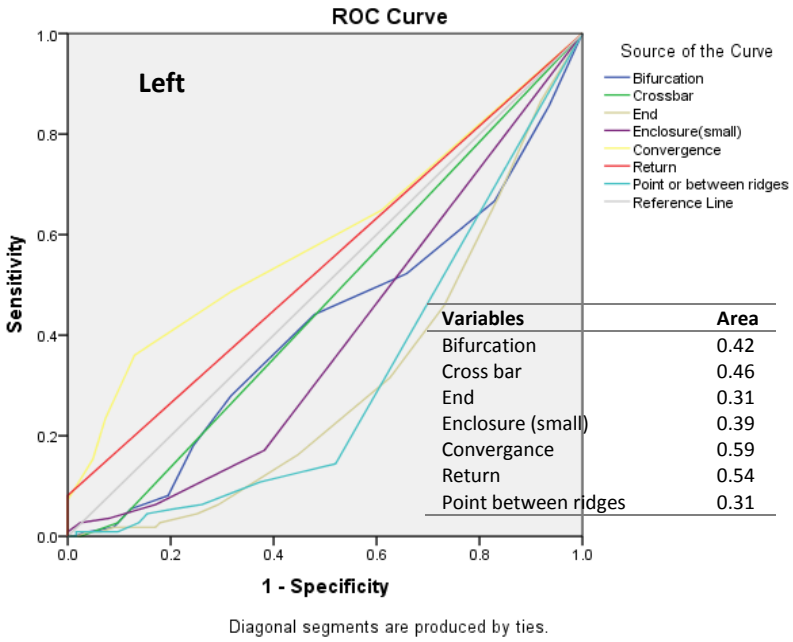


Figure 4.8: Receiver operating characteristics curve for determination of best model for sex discrimination using minutiae types of the right thumbprint

4.2.3 Using facial linear dimension and angles

All the facial linear dimensions showed significant sexual dimorphism, except interocular distance, upper facial width, philtrum length, lower vermilion width, left and right orbital width (Table 4.6). With regards to sexdiscrimination, upper facial width was the best discriminator of sex with anaccuracy of 76.2% and 24-33% contribution to the prediction. However, the percentage accuracy increased to 91% when six variables (upper facial height I, special upper facial width, nasal width, lower facial width, mouth width, right orbital width) were included in the equations and percentages contribution of 56-75% (Table 4.7). For predicted probabilities of BLR for the variables that contributed best to the prediction shows that only upper facial height, left and right orbital width (Figure 4.9) were good predictor with ahigher area under the curve above 0.5.

For facial angles, only nasion and aperture modified angle did not show significant gender differences (Table 4.6). However, in the variable with significant gender differences only nasomental angle shows some level of sex discrimination with anaccuracy of 70.3% and 20.7-27.6 contribution to the prediction (Table 4.7). The ROC curve analyses show that naso-mental angles have area under curve of > 0.5, indicating good probability of the model (Figure 4.9).

Table 4.6:Sexual dimorphism in facial linear dimensions and angles

	Male	**Female**		
Variables (mm)	Mean ± SD	Mean ± SD	t	P-Value
Special face height	100.88 ± 6.78	97.66 ± 5.98	4.225	<0.001
Upper facial height	40.67 ± 4.19	45.61 ± 4.40	-9.662	<0.001
Lower facial height	62.98 ± 5.22	58.05 ± 5.06	8.055	<0.001
Special upper height I	83.45 ± 5.52	80.66 ± 6.02	4.069	<0.001
Inter ocular distance	31.72 ± 3.12	31.08 ± 3.11	1.735	0.084
Nasal width	40.68 ± 3.11	38.05 ± 3.11	7.12	<0.001
Upper facial width	116.83 ± 8.90	118.3 ± 7.03	-1.532	0.127
Philtrum length	12 ± 2.14	11.99 ± 1.77	0.027	0.978
Lower facial width	104.9 ± 7.71	101.14 ± 7.98	4.031	<0.001
Upper lip length	22.95 ± 2.28	21.59 ± 2.12	5.187	<0.001
Height of lower 1/3 of face	40.05 ± 4.11	36.47 ± 4.17	7.258	<0.001
Mouth width	23.79 ± 2.80	22.2 ± 2.62	4.93	<0.001
Mouth width	50.4 ± 4.15	47.3 ± 3.15	7.055	<0.001
Upper vermilium width	10.97 ± 1.47	9.62 ± 1.64	7.303	<0.001
Lower vermilium width	12.84 ± 2.14	12.59 ± 1.75	1.058	0.291
Right orbital width	11.5 ± 1.40	12.67 ± 1.51	-6.756	<0.001
Left orbital width	11.61 ± 1.49	12.59 ± 1.50	-5.532	<0.001
Right orbital length	29.14 ± 2.31	29.3 ± 1.89	-0.645	0.519
Left orbital length	29.08 ± 2.07	29.22 ± 2.08	-0.561	0.575
Right zygon to gnathion	101.49 ± 6.59	98.92 ± 6.38	3.332	0.001
Left zygon to gnathion	101.51 ± 7.36	98.73 ± 6.87	3.288	0.001
Aperture Modified angle	48.24 ± 2.73	48.2 ± 2.12	0.114	0.909
Nasion angle	78.67 ± 5.31	78.87 ± 5.29	-0.324	0.746
Nasofrontal angle	139.94 ± 6.79	142.35 ± 6.54	-3.029	0.003
Mentocervical angle	82.61 ± 5.67	87.11 ± 8.05	-5.466	<0.001
Nasofacial angle	38.58 ± 3.83	37.27 ± 3.42	3.034	0.003
Nasomental angle	104.46 ± 11.17	116.31 ± 12.88	-8.283	<0.001

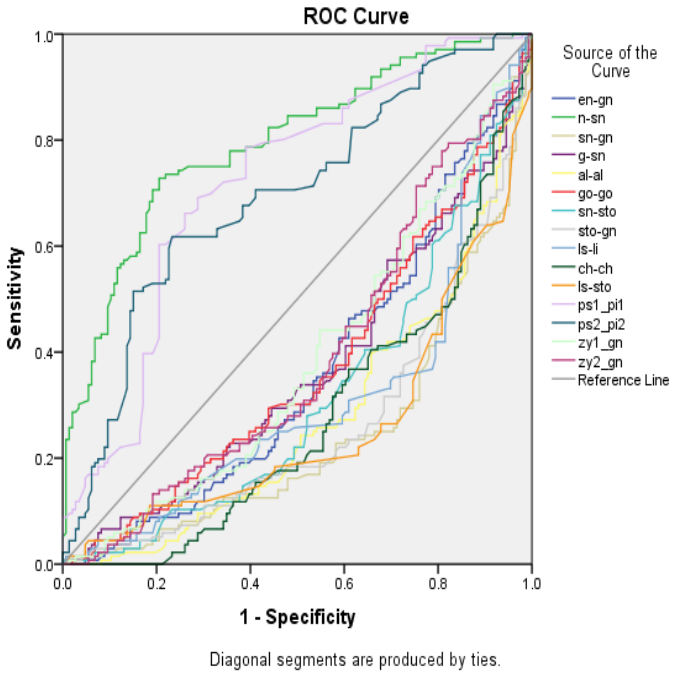
SD: Standard diviation

Table 4.7: Generated equations for sex discrimination using linear facial dimensions

Steps	Equations (y=mx + c)	Accuracy (%)	-2 Log likelihood	Cox and Snell R^2	Nagelkerke R^2	$\chi 2$
1	Sex =-0.274(Upper facial height) + 11.926	76.2	310.128	0.248	0.331	80.453*
2	Sex =-0.504(Upper facial height)+ 0.294(Special upper facial height I) -2.245	82.6	228.011	0.438	0.584	162.570*
3	Sex =-0.525(Upper facial height)+ 0.227(Special upper facial height I) + 0.269(Mouth width) -9.067	86.5	198.948	0.493	0.658	191.632*
4	Sex =-0.489(Upper facial height)+ 0.214(Special upper height I) + 0.302(Mouth width)+ (-0.558)(right orbital width) -4.53	88.7	181.207	0.524	0.699	209.373*
5	Sex =-0.489(Upper facial height)+ 0.177(Special upper height I) + 0.238(al-al)+0.24(Mouth width)+ (-0.599)(right orbital width) -7.279	87.9	170.392	0.542	0.723	220.188*
6	Sex =-0.56(Upper facial height)+ 0.297(Special upper height I) + 0.307(Nasal width) + (-0.134)(Lower facial width)+0.264(Mouth width)+ (-0.592)(Orbital width) -4.249	91.1	156.583	0.564	0.752	233.998*
1	Sex = Nasomental angle (-0.093) + 10.26	70.3%	-	0.207	0.276,	65.63*

The cut value is 0.5 (negative value indicate female), *p< 0.05

Variables	Area
en-gn	0.362
n-sn	0.793
sn-gn	0.242
g-sn	0.365
al-al	0.277
go-go	0.371
sn-sto	0.315
sto-gn	0.262
ls-li	0.312
ch-ch	0.278
ls-sto	0.258
ps1_pi1	0.72
ps2_pi2	0.692
zy1_gn	0.385
zy2_gn	0.389



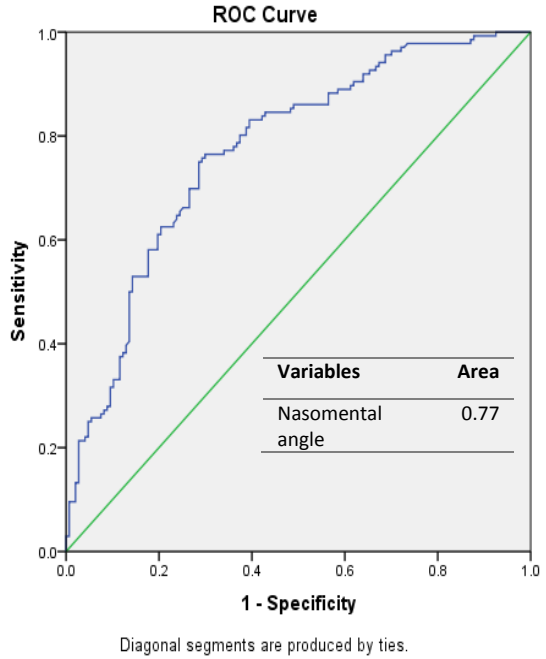


Figure 4.9: Receiver operating characteristics curve for determination of best model for sex discrimination using linear facial dimension and angles

4.3 FLUCTUATING ASYMMETRY IN THUMBPRINTS AND FACIAL PROFILES

4.3.1 SexualDimorphism in Asymmetry Indices of Thumbprints and Facial Profiles

Table 4.8-4.11 show the sexdifferences in asymmetry indices of minutiae counts. It was observed that a significant ($P < 0.05$)difference in signed asymmetry (SA) occurred in abifurcation, cross bar, break, bridge, point/dot into ridges and point/dot between the ridges. For both absolute asymmetry (AA) and composited asymmetry (CA), the significant differences were noticed in similar minutiae types; end, enclosure small, bridges, and return, with theexception of thecross bar and opposite bifurcation for absolute symmetry, and convergence and fragment big for composited asymmetry. In all the minutiae type, females tend to have higher mean value, except for end (in AA and CA), enclosure small (in AA and CA), opposite bifurcation (in AA only).

As shown in Table 4.12 there were significant sexdifferences in CA in all ridge densities (ulna, radial and proximal) and thickness (ulna, radial and proximal). However, for signed asymmetry, it was observed only in ulnar ridge density and thickness. For absolute asymmetry, in addition to the ulna ridge density, differencesoccurred in proximal ridge density and thickness.

With respect to facial dimension, no significance differences were observed in signed asymmetry in the three facial dimensions (Figure 4.10). However, significantly higher mean differences were observed in zygon to gnathion facial dimension in both absolute asymmetry (Table 4.11) and composited asymmetry (Table 4.12).

4.3.2 Assessment of Fluctuating Asymmetry in Thumbprints and Facial Profiles

Using one sample t - test only, bifurcation exhibited directional asymmetry ($P < 0.05$) in male and six different minutiae type; end, break, enclosure small, point/dot into ridges and point/dot between ridges, in thefemale. For ridge density, all the variables in both sexes exhibited fluctuating asymmetry. Further evaluation of fluctuating asymmetry, normality test showed that both minutiae and ridge density show significant skewness and kurtosis in the signed asymmetry(Table 4.8-4.12). For the facial dimension, one sample t - test revealed level of fluctuating asymmetry in facial dimension, with signed asymmetry of the variable not significantly greater than themean of zero. The normality test, however, showed that orbital width and zygon to gnathion poor indicator of fluctuation asymmetry. Mixed model ANOVA (Split-plot ANOVA) for assessment of repeatability asymmetry showed no significant interaction between differences in the repeatability of measurement and signed asymmetry in the facial variables; orbital width, orbital length, zygon to gnathion, and zygon to thevertex (Figure 4.10).

Table 4.8: Sexual dimorphism in asymmetry indices of thumbprint minutiae (category A)

Minutiae Types	Asymmetry Index	Male	Female		
		Mean ± SD	Mean ± SD	t	P-value
Bifurcation	Signed (1)	-0.96 ± 3.02	-0.03 ± 2.94	-2.31	0.022
	Absolute	2.29 ± 2.18	2.26 ± 1.88	0.10	0.918
	Composited	0.02 ± 0.02	0.02 ± 0.02	-0.43	0.669
Cross-bar	Signed	-0.10 ± 0.57	0.05 ± 0.32	-2.3	0.022
	Absolute	0.21 ± 0.54	0.09 ± 0.31	1.98	0.049
	Composited	0.002 ± 0.005	0.001 ± 0.003	1.86	0.065
Trifurcation convergence	Signed	0.01 ± 0.21	0.02 ± 0.24	-0.33	0.742
	Absolute	0.04 ± 0.21	0.04 ± 0.24	0.22	0.829
	Composited	0.0003 ± 0.00	0.0004 ± 0.002	-0.13	0.894
Trifurcation bifurcation	Signed (1)	-0.05 ± 0.26	-0.02 ± 0.31	-0.89	0.376
	Absolute	0.07 ± 0.26	0.08 ± 0.30	-0.13	0.900
	Composited	0.001 ± 0.002	0.001 ± 0.003	-0.25	0.803
End	Signed (2)	0.20 ±4.65	0.52 ± 2.60	-0.64	0.526
	Absolute	3.55 ± 2.98	1.95 ± 1.78	4.76	<0.001
	Composited	0.03 ± 0.03	0.02 ± 0.02	4.30	<0.001

SD; standard diviation, Signed asymmetry = R-L, Absolute asymmetry = $\sqrt{}$ (R-L) 2, Composited asymmetry = $\sum\sqrt{}$(R-L) 2/n, L; left, R; right, n; sample size. (1): the mean value is significantly greater than zero in males, (2): the mean value is significantly greater than zero in females

Table 4.9: Sexual dimorphism in asymmetry indices of thumbprint minutiae (category B)

Minutiae Type	Asymmetry Index	Male	Female		
		Mean ± SD	Mean ± SD	t	P- value
Break	Signed (2)	-0.14 ± 2.00	0.72 ±1.88	-3.28	0.001
	Absolute	1.18 ± 1.62	1.35 ± 1.49	-0.82	0.413
	Composited	0.01 ± 0.01	0.01 ± 0.01	-1.21	0.228
Enclosure (big)	Signed	0.20 ± 1.73	-0.17 ± 1.36	1.73	0.084
	Absolute	1.21 ± 1.24	0.95 ± 0.98	1.72	0.088
	Composited	0.01 ± 0.01	0.01 ± 0.01	1.27	0.206
Enclosure (small)	Signed (2)	0.21 ± 1.75	0.33 ± 1.13	-0.64	0.525
	Absolute	1.17 ± 1.31	0.66 ± 0.98	3.25	0.001
	Composited	0.01 ± 0.01	0.01 ± 0.01	2.91	0.004
Bridge	Signed	-0.05 ± 0.58	0.07 ± 1.11	-1.01	0.315
	Absolute	0.27 ± 0.52	0.60 ± 0.94	-3.26	0.001
	Composited	0.002 ± 0.005	0.01 ± 0.01	-3.47	0.001
Opposite bifurcation.	Signed (2)	-0.03 ± 0.68	-0.15 ± 0.50	1.55	0.123
	Absolute	0.37 ± 0.57	0.23 ± 0.47	1.94	0.054
	Composited	0.00 ± 0.01	0.002 ± 0.004	1.68	0.094

SD; standard diviation, Signed asymmetry = R-L, Absolute asymmetry = $\sqrt{}$ (R-L) 2, Composited asymmetry = $\sum\sqrt{}$(R-L) 2/n, L; left, R; right, n; sample size (2): the mean value is significantly greater than zero in females

Table 4.10: Sexual dimorphism in asymmetry indices of thumbprint minutiae (category C)

Minutiae Type	Asymmetry Index	Male	Female		
		Mean ± SD	Mean ± SD	t	P-value
Dock	Signed	0.04 ± 0.37	0.01 ± 0.35	0.72	0.473
	Absolute	0.08 ± 0.36	0.10 ± 0.34	-0.52	0.607
	Composited	0.00 ± 0.003	0.001 ± 0.003	-0.64	0.521
in "M" convergence	Signed (1)	-0.04 ± 0.19	0.04 ± 0.57	-1.3	0.196
	Absolute	0.04 ± 0.19	0.13 ± 0.56	-1.77	0.08
	Composited	0.0003 ± 0.00	0.001 ± 0.01	-1.81	0.072
in "M" bifurcation	Signed	-0.04 ± 0.34	-0.03 ± 0.26	-0.39	0.696
	Absolute	0.12 ± 0.32	0.07 ± 0.25	1.26	0.21
	Composited	0.001 ±0.003	0.001 ±0.002	1.12	0.266
Convergence	Signed	0.15 ±1.89	-0.24 ±2.35	1.35	0.178
	Absolute	1.44 ±1.23	1.74 ±1.58	-1.59	0.112
	Composited	0.01 ±0.01	0.02 ±0.02	-2.11	0.036
Over lap	Signed (1)	0.14 ±0.70	0.02 ±0.60	1.4	0.164
	Absolute	0.36 ±0.61	0.27 ±0.54	1.15	0.252
	Composited	0.003 ±0.01	0.003 ±0.01	0.9	0.37

SD; standard diviation, Signed asymmetry = R-L, Absolute asymmetry = $\sqrt{}$ (R-L) 2, Composited asymmetry = $\sum\sqrt{}$(R-L) 2/n, L; left, R; right, n; sample size.(1): the mean value is significantly greater than zero in males

Table 4.11: Sexual dimorphism in asymmetry indices of thumbprint minutiae (category D)

Minutiae Type	Asymmetry Index	Male	Female		
		Mean ± SD	Mean ± SD	T	P-value
Fragment big	Signed	0.04 ± 1.01	0.00 ± 1.43	0.27	0.789
	Absolute	0.53 ± 0.86	0.76 ± 1.21	-1.66	0.098
	Composited	0.005 ± 0.01	0.01 ± 0.01	-1.94	0.054
Fragment small	Signed	0.14 ± 1.35	0.26 ± 1.69	-0.55	0.582
	Absolute	0.68 ± 1.17	0.81 ± 1.51	-0.72	0.474
	Composited	0.01 ± 0.01	0.01 ± 0.01	-0.97	0.332
Return	Signed	0.02 ± 0.13	-0.01 ± 0.45	0.62	0.538
	Absolute	0.02 ± 0.13	0.12 ± 0.43	-2.48	0.014
	Composited	0.0002 ± 0.001	0.001 ± 0.004	-2.52	0.013
Point/Dot into ridges	Signed (2)	-0.13 ± 1.22	0.15 ± 0.50	-2.16	0.032
	Absolute	0.29 ± 1.20	0.15 ± 0.50	1.06	0.29
	Composited	0.00 ± 0.01	0.00 ± 0.00	0.97	0.333
Point/Dot between ridges	Signed (2)	0.48 ± 3.39	1.39 ± 3.38	-1.98	0.049
	Absolute	2.25 ± 2.57	1.94 ± 3.09	0.8	0.425
	Composited	0.02 ± 0.02	0.02 ±0.03	0.45	0.657

SD; standard diviation, Signed asymmetry = R-L, Absolute asymmetry = $\sqrt{}$ (R-L) 2, Composited asymmetry = $\sum\sqrt{}$(R-L) 2/n, L; left, R; right, n; sample size.(2): the mean value is significantly greater than zero in females

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Table 4.12: Sexual dimorphism in asymmetry indices of thumbprint ridge density

Ridge Density	Asymmetry Index	Male	Female	t	P-value
		Mean ± SD	Mean ± SD		
Ulna ridge density	Signed*	-0.27 ± 1.50	0.33 ± 1.84	-2.48	0.014
	Absolute	1.09 ± 1.06	1.43 ± 1.20	-2.06	0.041
	Composited	0.01 ± 0.01	0.02 ± 0.01	-3.34	0.001
Ulna ridge thickness	Signed*	0.01 ± 0.11	-0.02 ± 0.13	1.92	0.057
	Absolute	0.08 ± 0.08	0.09 ± 0.09	-1.3	0.195
	Composited	0.0007 ± 0.0008	0.0010 ± 0.0011	-2.45	0.015
Radial ridge density	Signed*	-0.13 ± 1.79	-0.35 ± 1.99	0.82	0.411
	Absolute	1.38 ± 1.13	1.50 ± 1.35	-0.66	0.512
	Composited	0.01 ± 0.01	0.02 ± 0.02	-2.06	0.041
Radial ridge thickness	Signed*	0.01 ± 0.12	0.03 ± 0.17	-1.16	0.247
	Absolute	0.09 ± 0.08	0.12 ± 0.12	-1.82	0.071
	Composited	0.0009 ± 0.0007	0.0013 ± 0.0014	-2.96	0.003
Proximal ridge density	Signed*	0.04 ± 1.35	0.48 ± 2.27	-1.64	0.102
	Absolute	1.03 ± 0.87	1.75 ± 1.51	-4.17	<0.001
	Composited	0.01 ± 0.01	0.02 ± 0.02	-6.83	<0.001
Proximal ridge thickness	Signed*	0.00 ± 0.11	-0.04 ± 0.21	1.496	0.136
	Absolute	0.08 ± 0.07	0.15 ± 0.15	-4.56	<0.001
	Composited	0.00075 ± 0.00067	0.0017 ± 0.0017	-5.51	<0.001

SD; standard diviation, Signed asymmetry = R-L, Absolute asymmetry = $\sqrt{(R-L)}$ 2, Composited asymmetry = $\sum\sqrt{(R-L)}$ 2/n, L; left, R; right, n; sample size, *The mean value (in signed) in both sexes not greater than zero

The mean value (in signed asymmetry) in both sexes was not greater than zero. Normality test P > 0.05.

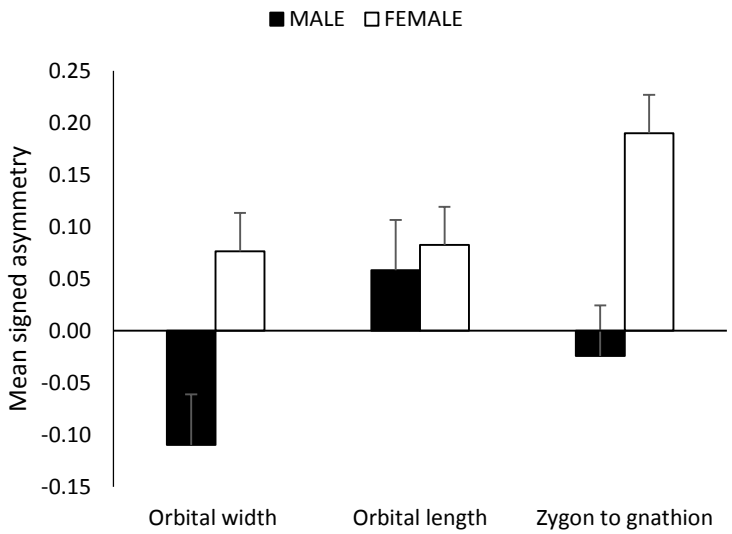


Figure 4.10: Sexual dimorphism in signed asymmetry (SA) of the paired facial dimensions

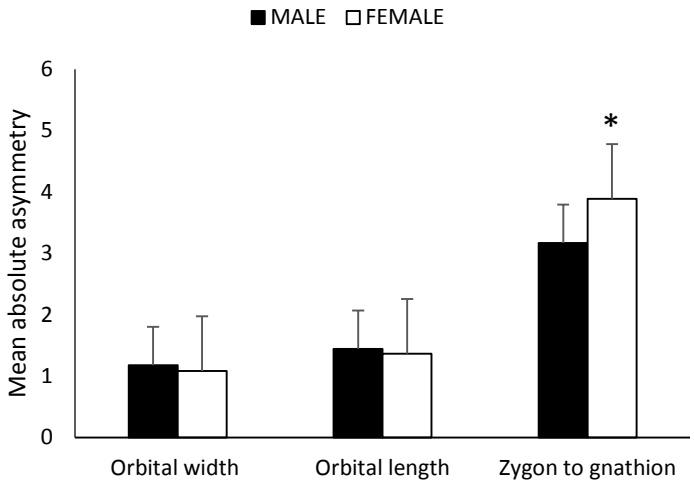


Figure 4.11: Sexual dimorphism in absolute asymmetry of the paired facial dimensions (*P < 0.05)

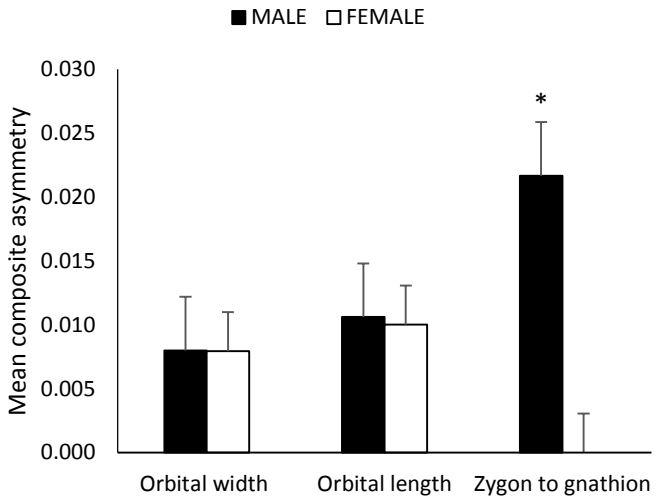


Figure 4.12: Sexual dimorphism in composited asymmetry of the paired facial dimensions (*P < 0.05)

4.4 ASSOCIATION OF THUMBPRINT PATTERN AND FACIAL PROPORTION

From Table 4.13 in both males and females, no occurrence of classical canon of facial proportion. There was also no significant association between gender and facial proportion. However, thefemales had higher percentages of the variant of the canon, compared to the male in all classes.

No significant association was obtained between the thumbprint pattern of the right and left thumb with both vertical (Table 4.14) and horizontal (Table 4.15) facial proportion in males participants except for four section canon. In females, there was also no significant association between the horizontal facial proportion and thumbprints (Table 4.16).

Table 4.13: Neoclassical facial proportion (vertical) in male and female

Classes	Canon and variations	Male (%)	Female (%)	$\chi 2$
V	Inter ocular distance = Nasal width	0 (0)	0 (0)	2.183
	Inter ocular distance > Nasal width	0 (0)	4 (100)	
	Inter ocular distance < Nasal width	147 (35.4)	268 (64.6)	
VI	Inter ocular distance = Orbital length	0 (0)	0 (0)	1.155
	Inter ocular distance > Orbital length	111 (36.6)	192 (63.4)	
	Inter ocular distance < Orbital length	36 (31)	80 (69)	
VII	Mouth width = 1.5 (Nasal width)	0 (0)	0 (0)	1.855
	Mouth width > 1.5 (Nasal width)	1 (100)	0 (0)	
	Mouth width < 1.5 (Nasal width)	146 (34.9)	272 (65.1)	
VIII	Nasal width= 0.25 (Upper facial width)	0 (0)	0 (0)	
	Nasal width > 0.25 (Upper facial width)	147 (35.1)	272 (64.9)	-
	Nasal width < 0.25 (Upper facial width)	0 (0)	0 (0)	

Table 4.14: Association between thumbprints pattern and facial proportion (vertical) in male

		Right thumbprint (%)				Left thumbprint (%)				
Class	Canon and variations	Arch	Whorl	Loop	FE Value	Arch	Whorl	Loop	FE Value	Overall FE Value
I	SHH=SFH	0 (0)	0 (0)	0 (0)	0.34	0 (0)	0 (0)	0 (0)	0.09	0.07
	SHH> SFH	7 (4.2)	71 (42.5)	89 (53.3)		14 (8.9)	60 (38)	84 (53.2)		
	SHH< SFH	11 (5)	97 (44.3)	111 (50.7)		17 (8.2)	78 (37.7)	112 (54.1)		
II	FH II = UFH = LFH	0 (0)	0 (0)	0 (0)	2.2	0 (0)	0 (0)	0 (0)	1.25	1.77
	UFH < LFH	18 (4.7)	168 (43.6)	199 (51.7)		31 (8.5)	138 (37.9)	195 (53.6)		
	FH II >LFH	0 (0)	0 (0)	1 (100)		0 (0)	0 (0)	1 (100)		
	FH II < LFH	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		
	FH II >LFH	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		
III	HC= FH I=SUFH I=LFH	0 (0)	0 (0)	0 (0)	6.22	0 (0)	0 (0)	0 (0)	7.59	11.76*
	HC<FH I	17 (4.5)	165 (43.5)	197 (52)		29 (8.1)	135 (37.7)	194 (54.2)		
	HC<SUFH I	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		
	HC<LFH	1 (20)	1 (20)	3 (60)		2 (40)	1 (20)	2 (40)		
	HC>FH I	0 (0)	2 (100)	0 (0)		0 (0)	2 (100)	0 (0)		
	FH I> SUFH	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		
	FH I< LFH	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		
	SUFH<LFH	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		

FE; Fisher's Exact SHH; special head height, SFH; special face height, FH II; forehead height II, UFH; upper facial height, LFH; lower facial height, HC; height of calva, SUFH I; special upper face height I, FH I; forehead height I, LFH; lower facial height * P < 0.05

Table 4.15: Association between thumbprints pattern and facial proportion (horizontal) in male

Classes	Canon and variations	Right thumbprint (%)			FE Value	Left thumbprint (%)			FE Value	Overall FE Value
		Arch	Whorl	Loop		Arch	Whorl	Loop		
	IOD=NW	0 (0)	0 (0)	0 (0)	NA	0 (0)	0 (0)	0 (0)	NA	NA
	IOD>NW	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		
V	IOD<NW	18 (4.7)	168 (43.5)	200 (51.8)		31 (8.5)	138 (37.8)	196 (53.7)		
	IOD=OL	0 (0)	0 (0)	0 (0)	3.17	0 (0)	0 (0)	0 (0)	2.08	1.16
	IOD>OL	10 (7)	63 (44.4)	69 (48.6)		11 (8.1)	45 (33.3)	79 (58.5)		
VI	IOL<OL	8 (3.3)	105 (43)	131 (53.7)		20 (8.7)	93 (40.4)	117 (50.9)		
	MW=1.5(NW)	0 (0)	0 (0)	0 (0)	1.14	0 (0)	0 (0)	0 (0)	0.43	0.25
	MW>1.5(NW)	0 (0)	2 (66.7)	1 (33.3)		0 (0)	1 (33.3)	2 (66.7)		
VII	MW<1.5(NW)	18 (4.7)	166 (43.3)	199 (52)		31 (8.6)	137 (37.8)	194 (53.6)		
	NW=0.25(UFW)	0 (0)	0 (0)	0 (0)	NA	0 (0)	0 (0)	0 (0)	NA	NA
	NW>0.25(UFW)	18 (4.7)	168 (43.5)	200 (51.8)		31 (8.5)	138 (37.8)	196 (53.7)		
VIII	NW<0.25(UFW)	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		

FE; Fisher's Exact, IOD; interocular distance, NW; nasal width, OL; orbital length, MW; mouth width, UFW; upper facial width, NA: not available

Table 4. 16: Association between thumbprints pattern and facial proportion (vertical) in female

Classes	Canon and variations	Right thumbprint (%)			FE Value	Left thumbprint (%)			FE Value	Overall FE Value
		Arch	Whorl	Loop		Arch	Whorl	Loop		
V	IOD=NW	0 (0)	0 (0)	0 (0)	1.19	0 (0)	0 (0)	0 (0)	4.81	3.53
	IOD>NW	0 (0)	1 (50)	1 (50)		1 (50)	1 (50)	0 (0)		
	IOD<NW	6 (4.7)	49 (38.6)	72 (56.7)		8 (6.6)	48 (39.7)	65 (53.7)		
VI	IOD=OL	0 (0)	0 (0)	0 (0)	0.24	0 (0)	0 (0)	0 (0)	3.59	1.57
	IOD>OL	4 (4.4)	35 (38.5)	52 (57.1)		9 (10)	35 (38.9)	46 (51.1)		
	IOL<OL	2 (5.3)	15 (39.5)	21 (55.3)		0 (0)	14 (42.4)	19 (57.6)		
VII	MW=1.5(NW)	0 (0)	0 (0)	0 (0)	NA	0 (0)	0 (0)	0 (0)	NA	NA
	MW>1.5(NW)	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		
	MW<1.5(NW)	6 (4.7)	50 (38.6)	73 (56.6)		9 (7.3)	49 (39.8)	65 (52.8)		
VIII	NW=0.25(UFW)	0 (0)	0 (0)	0 (0)	NA	0 (0)	0 (0)	0 (0)	NA	NA
	NW>0.25(UFW)	6 (4.7)	50 (38.8)	73 (56.6)		9 (7.3)	49 (39.8)	65 (52.8)		
	NW<0.25(UFW)	0 (0)	0 (0)	0 (0)		0 (0)	0 (0)	0 (0)		

FE; Fisher's Exact, IOD; interocular distance, NW; nasal width, OL; orbital length, MW; mouth width, UFW; upper facial width, NA: not available.

4.5 CORRELATIONS BETWEEN THUMBPRINTS' MINUTIAE AND FACIAL PROFILES

TableS 4.17-4.22 showed correlations between different minutiae type with facial linear dimensions, angle, and ratio in both sexes and sides of the thumb. In the right thumbprints each of the minutiae, the type have correlation with either one or more facial variables except for bifurcation, trifurcation bifurcation (Tables 4.17-4.19). in the left thumbprints, the ridge eding, trifurcate bifurcation and cross-bar correlated with facial variables as shown in Tables 4.20 – 4.22.

Table 4.17: Correlations between right minutiae types (category A) with facial dimension (category I) (male-up and female-down)

Right T.	**Bifur**	**C.bar**	**Tri C**	**Tri B**	**End**	**n-sn**	**sn-gn**	**g-sn**	**en-en**	**al-al**	**zy-zy**	**sn-ls**	**go-go**	**sn-sto**	**sto-gn**
Bifur	-	-0.094	-0.025	-0.073	-0.175**	0.06	0.014	0.031	-0.016	0.031	-0.021	-0.017	-0.013	-0.02	0.025
C.bar	-0.176	-	-0.029	0.072	0.083	-0.012	-0.051	0.03	-0.047	0.048	0.029	-0.029	0.006	0.009	-0.064
Tri C	-0.097	0.167	-	.213**	-0.046	-0.120*	-0.039	-0.095	0.073	-0.082	-0.028	-0.003	0.09	-0.003	-0.047
Tri B	0.173	-0.041	-0.029	-	-0.06	-0.053	0.082	0.015	-0.072	0.036	-0.006	0.038	-0.014	0.065	0.064
End	0.172	0.002	0.00s1	-0.094	-	-0.01	-0.078	-0.006	0.018	0.042	0.00	-0.037	0.035	-0.035	-0.077
n-sn	-0.071	0.175	0.073	0.06	-0.019	-	.219**	.630**	0.035	0.523**	0.456**	0.025	-0.184**	.142**	0.194**
sn-gn	0.007	0.144	-0.016	0.026	0.149	0.009	-	.703**	0.145**	0.480**	0.514**	0.348**	.265**	.659**	0.902**
g-sn	-0.05	0.265**	0.002	0.065	0.125	0.548**	0.632**	-	0.04	0.655**	0.602**	0.116**	0.006	.425**	0.654**
en-en	-0.038	0.235*	0.149	0.113	0.01	0.343**	0.345**	0.496**	-	0.190**	0.352**	0.129**	0.468**	.154**	0.099
al-al	0.002	0.132	0.031	0.092	-0.117	0.324**	0.249**	0.426**	0.487**	-	0.581**	0.107**	0.056	.312**	0.431**
zy-zy	-0.088	0.190*	0.035	0.08	0.055	0.367**	0.590**	0.709**	0.641**	0.538**	-	0.140**	0.332**	.324**	0.475**
sn-ls	0.033	-0.1	0.073	0.042	0.072	0.043	0.189*	0.207*	0.063	0.04	0.096	-	0.134**	.689**	0.05
go-go	0.011	0.113	-0.021	0.062	0.12	0.134	0.658**	0.651**	0.425**	0.417**	0.802**	0.043	-	.106**	0.277**
sn-sto	0.022	0.051	0.003	0.047	0.14	-0.003	0.592**	0.441**	0.280**	0.174*	0.342**	0.661**	0.284**	-	0.275**
sto-gn	-0.004	0.15	-0.021	0.009	0.109	0.013	0.912**	0.543**	0.277**	0.214*	0.543**	-0.106	0.654**	0.210**	-

Bifur; bifurcation, C. bar; cross bar, Tri C; trifurcation, Tri B; trifurcation, n-sn; nasal length/ upper facial height, sn-gn; lower facial height, g-sn; special upper height I, en-en; inter ocular distance, al-al; nasal width, zy-zy; upper facial width; sn-ls; philtrum length, go-go; lower facial width, sn-sto; upper lip length, sto-gn; lower lip length, T; thumb, **P < 0.01, * P < 0.05

Table 4. 18: Correlations between right minutiae types (category A) with facial dimension (category II) (male-up and female-down)

Right T.	**Bifur**	**C.bar**	**Tri C**	**Tri B**	**End**	**ls-li**	**ch-ch**	**ls-sto**	**sto-li**	**ps1_pi1**	**ps2_pi2**	**ex1_en1**	**ex2_en2**	**zy1_gn**	**zy2_gn**
Bifur	-	-0.094	-0.025	-0.073	-0.175**	0.044	0.031	-0.008	0.072	-0.011	-0.015	0.04	0.028	0.017	0.029
C.bar	-0.176	-	-0.029	0.072	0.083	0.022	0.004	0.048	-0.012	0.113*	0.034	0.087	0.036	-0.011	-0.057
Tri C	-0.097	0.167	-	0.213**	-0.046	0.005	-0.04	0.001	0.007	-0.095	-0.074	-0.084	-0.086	-0.085	-0.120*
Tri B	0.173	-0.041	-0.029	-	0.06	0.089	0.025	0.053	0.081	0.015	-0.019	-0.002	-0.009	0.013	0.006
End	0.172	0.002	0.001	-0.094	-	0.036	0.009	-0.001	0.055	0.074	0.1	0.057	0.089	-0.049	-0.032
ls-li	-0.049	0.178	-0.034	0.007	0.15	-	.433**	0.785**	0.870**	0.324**	0.323**	0.450**	0.476**	0.520**	0.514**
ch-ch	-0.125	0.137	0.065	0.065	-0.16	0.485**	-	0.295**	0.422**	0.380**	0.354**	0.564**	0.562**	0.577**	0.577**
ls-sto	-0.008	0.176	-0.075	0.016	0.105	0.753**	0.326**	-	0.391**	0.246**	0.179**	0.330**	0.351**	0.365**	0.363**
sto-li	-0.064	0.091	0.023	-0.006	0.121	0.791**	0.422**	0.193*	-	0.282**	0.344**	0.415**	0.429**	0.487**	0.487**
ps1_pi1	0.023	0.11	0.141	-0.069	0.066	0.065	0.175*	0.034	0.065	-	0.703**	0.576**	0.589**	0.445**	0.375**
ps2_pi2	-0.177	0.192*	0.03	-0.042	-0.073	0.028	0.148	-0.085	0.121	0.554**	-	0.527**	0.575**	0.424**	0.400**
ex1_en1	-0.105	0.105	0.207*	0.029	-0.016	0.187*	0.416**	0.147	0.142	0.393**	0.348**	-	0.863**	0.662**	0.614**
ex2_en2	-0.017	-0.042	-0.037	-0.011	0.009	0.221**	0.445**	0.13	0.209*	0.317**	0.373**	0.588**	-	0.648**	0.646**
zy1_gn	-0.086	0.179	0.126	-0.015	0.136	0.457**	0.395**	0.311**	0.392**	0.216*	0.245**	0.488**	0.390**	-	0.879**
zy2_gn	-0.101	0.149	0.08	0.065	0.014	0.464**	0.441**	0.308**	0.405**	0.220*	0.262**	0.471**	0.545**	0.734**	-

Bifur; bifurcation, C. bar; cross bar, Tri C; trifurcation, Tri B; trifurcation, ls-li; mouth width, ch-ch; mouth width, ls-sto; upper vermilium width, sto-li; lower vermilium width, ps1-pi1; right orbital width, ex1-en1; right orbital length, ps2-pi2; left orbital width, ex2-en2; left orbital length, zy1-v; right zygon to vertex; zy2-v; left zygon to vertex; zy1-gn; right zygon to gnathion; zy2-gn; left zygon to gnathion;**P < 0.01, * P < 0.05

Table 4.19: Correlations between right minutiae types (category A) with facial angle and ratio (male-up and female-down)

Right T.	Bifur	C.bar	Tri C	Tri B	End	APM	NA	NFrA	MCA	NFcA	NMA	UFW/LFW	UFW/UFH	LFH/FH	UFW/LFH
Bifurcation	-	-0.094	-0.025	-0.073	-0.18**	0.002	-0.026	0.021	-0.04	0.078	-0.028	0.005	-0.091	-0.046	-0.039
Cross bar	-0.176	-	-0.029	0.072	0.083	0.101	0.001	-0.024	-0.004	-0.034	-0.01	0.03	0.02	-0.029	0.08
Tri C	-0.097	0.167	-	0.213**	-0.046	0.067	0.139*	-0.003	0.022	0.062	0.018	-0.108	0.135*	0.089	0.016
Tri B	0.173	-0.041	-0.029	-	0.06	-0.038	-0.019	0.03	-0.065	-0.021	-0.01	0.007	0.053	0.105	-0.097
End	0.172	0.002	0.001	-0.094	-	0.129*	0.038	-0.071	0.158**	-0.025	0.042	-0.037	0.014	-0.042	0.083
APM	0.074	-0.092	0.074	0.053	-0.082	-	-0.022	-0.025	0.143**	-0.043	0.119*	0.071	0.165**	-0.110*	0.397**
NA	0.058	-0.094	-0.023	-0.033	0.047	0.241**	-	-0.19**	0.292**	0.384**	0.022	-0.819**	0.536**	0.320**	0.164**
NFrA	-0.028	0.107	0.077	-0.119	0.09	-0.116	-0.07	-	-0.40**	-0.32**	-0.13**	0.202**	-0.235**	-0.26**	0.114*
MCA	-0.064	-0.03	-0.026	0.021	-0.095	-0.092	0.077	-0.077	-	0.160**	0.668**	-0.279**	0.133**	0.079	0.054
NFcA	-0.026	-0.053	0.058	0.004	0.031	0.053	0.052	-0.42**	-0.104	-	-0.28**	-0.240**	0.201**	0.105*	0.088
NMA	-0.03	0.082	-0.084	0.084	-0.068	-0.198*	0.056	0.092	0.749**	-0.46**	-	-0.161**	0.069	0.157**	-0.159**
UFW/LFW	-0.131	0.056	0.068	-0.009	-0.129	0.068	-0.65**	-0.059	-0.163	0.054	-0.298**	-	-0.315**	-0.38**	0.225**
UFW/UFH	0.03	-0.067	-0.058	-0.014	0.066	0.201*	0.616**	-0.183*	-0.089	0.04	0.045	-0.283**	-	0.786**	0.01
LFH/FH	0.061	-0.032	-0.062	-0.021	0.112	-0.128	0.423**	-0.106	-0.125	0.014	0.1	-0.411**	0.858**	-	-0.605**
UFW/LFH	-0.082	-0.022	0.041	0.021	-0.129	0.511**	0.058	-0.066	0.117	0.039	-0.124	0.384**	-0.256**	-0.71**	-

Bifur; bifurcation, C. bar; cross bar, Tri C; trifurcation, Tri B; trifurcation, APM; aperture modified angle, NA; nasion angle; NFrA; nasofrontal angle, MCA; mentocervical, NFcA; nasofacial angle; NMA; nasomental angles, UFW/LFW; upper facial width to lower facial width, UFW/UFH; upper facial width to lower facial height, LFH/FH; lower facial height to facial height, UFW/LFH; upper facial width to lower facial height, T; Thumb,**P < 0.01, * p < 0.05

Table 4.20: Correlations between left minutiae types (category A) with facial dimension (category I) (male-up and female-down)

Left T	**Bifur**	**C.bar**	**Tri C**	**Tri B**	**End**	**n-sn**	**sn-gn**	**g-sn**	**en-en**	**al-al**	**zy-zy**	**sn-ls**	**go-go**	**sn-sto**	**sto-gn**
Bifur	-	-0.007	-0.088	0.110*	-0.039	-0.013	-0.05	-0.091	-0.096	-0.043	-0.079	0.005	0.02	-0.041	-0.045
C.bar	0.039	-	-0.032	-0.047	0.32**	0.001	-0.064	-0.065	0.06	0.005	-0.009	0.043	0.089	-0.022	-0.064
Tri C	0.022	-0.022	-	-0.036	-0.037	-0.034	0.006	-0.021	-0.03	-0.044	0.031	-0.045	-0.003	0.039	-0.006
Tri B	-0.007	-0.03	-0.024	-	-0.053	-0.014	0.1	0.049	0.025	-0.009	0.045	0.150**	0.031	0.103	0.075
End	0.023	0.05	-0.072	0.159	-	-0.25**	-0.14*	-0.20**	0.081	-0.18**	-0.130*	-0.037	0.169**	-0.051	-0.15**
n-sn	0.019	0.012	-0.009	-0.013	-0.018	-	0.215**	0.630**	0.036	0.519**	0.453**	0.024	-0.19**	0.137**	0.193**
sn-gn	0.094	-0.126	0.092	-0.004	0.041	0.009	-	0.703**	.144**	0.481**	0.515**	.348**	0.266**	0.660**	0.901**
g-sn	0.074	-0.027	0.039	0.045	0.008	0.55**	0.632**	-	0.036	0.653**	0.599**	.117*	0.004	0.425**	0.655**
en-en	0.082	-0.084	-0.042	-0.049	-0.035	0.343**	0.345**	0.496**	-	0.187**	0.349**	.129*	0.467**	0.153**	0.098
al-al	-0.059	-0.05	-0.1	0.074	-0.145	0.324**	0.249**	0.426**	.487**	-	0.579**	.108*	0.056	0.314**	0.431**
zy-zy	0.014	-0.151	-0.076	0.064	-0.005	0.367**	0.590**	0.709**	.641**	0.538**	-	.141**	0.332**	0.326**	0.475**
sn-ls	0.147	0.062	-0.014	0.015	0.029	0.043	0.189*	0.207*	0.063	0.04	0.096	-	0.135**	0.688**	0.05
go-go	0.067	-0.122	-0.026	0.047	-0.073	0.134	0.658**	0.651**	.425**	0.417**	0.802**	0.043	-	0.108*	0.277**
sn-sto	0.104	-0.037	0.018	0.034	0.098	-0.003	0.592**	0.441**	.280**	0.174*	0.342**	.661**	0.284**	-	0.275**
sto-gn	0.06	-0.133	0.102	-0.023	-0.002	0.013	0.912**	0.543**	.277**	0.214*	0.543**	-0.106	0.654**	0.210*	-

Bifur; bifurcation, C. bar; cross bar, Tri C; trifurcation, Tri B; trifurcation, n-sn; nasal length/ upper facial height, sn-gn; lower facial height, g-sn; special upper height I, en-en; inter ocular distance, al-al; nasal width, zy-zy; upper facial width; sn-ls; philtrum length, go-go; lower facial width, sn-sto; upper lip length, sto-gn; lower lip length, T; thumb**P < 0.01, * P < 0.05

Table 4.21: Correlations between right minutiae types (category A) with facial dimension (category II) (male-up and female-down)

Left T	Bifur	C.bar	Tri C	Tri B	End	ls-li	ch-ch	ls-sto	sto-li	ps1_pi1	ps2_pi2	ex1_en1	ex2_en2	zy1_gn	zy2_gn
Bifur	-	-0.007	-0.088	0.110*	-0.039	-0.039	-0.058	-0.058	-0.018	-0.046	-0.059	-0.053	-0.05	-0.059	**-0.053**
C.bar	0.039	-	-0.032	-0.047	0.317**	-0.098	-0.017	-0.081	-0.083	-0.14**	-0.019	-0.116*	-0.097	-0.063	**-0.047**
Tri C	0.022	-0.022	-	-0.036	-0.037	0.046	0.024	0.103	-0.023	0.059	0.052	0.046	0.062	0.018	**-0.003**
Tri B	-0.007	-0.03	-0.024	-	-0.053	0.019	0.096	-0.019	0.043	0.029	-0.011	-0.01	-0.009	0.09	**0.058**
End	0.023	0.05	-0.072	0.159	-	-0.12*	-0.24**	-0.021	-0.15**	-0.19**	-0.13*	-0.231**	-0.263**	-0.25**	**-0.27****
ls-li	0.025	-0.168	0.008	0.008	0.123	-	0.431**	0.786**	0.870**	0.321**	0.321**	0.448**	0.474**	0.518**	**0.512****
ch-ch	-0.063	-0.23*	-0.001	0.021	-0.094	0.485**	-	0.294**	0.420**	0.381**	0.353**	0.564**	0.561**	0.576**	**0.577****
ls-sto	-0.027	-0.114	0.037	0.028	0.096	0.753**	0.326**	-	0.393**	0.243**	0.180**	0.330**	0.350**	0.365**	**0.361****
sto-li	0.066	-0.141	-0.028	-0.017	0.091	0.791**	0.422**	0.193*	-	0.280**	0.342**	0.412**	0.427**	0.486**	**0.485****
ps1_pi1	-0.148	-0.142	-0.059	0.014	-0.04	0.065	0.175*	0.034	0.065	-	0.706**	0.581**	0.591**	0.445**	**0.375****
ps2_pi2	-0.22*	-0.009	-0.055	0.029	-0.034	0.028	0.148	-0.085	0.121	0.554**	-	0.524**	0.574**	0.423**	**0.401****
ex1_en1	-0.101	-0.22*	-0.046	0.025	-0.005	0.187*	0.416**	0.147	0.142	0.393**	0.348**	-	0.863**	0.663**	**0.616****
ex2_en2	0.053	-0.14	-0.158	-0.009	0.065	0.221**	0.445**	0.13	0.209*	0.317**	0.373**	0.588**	-	0.648**	**0.647****
zy1_gn	0.024	-0.137	0.113	0.037	0.063	0.457**	0.395**	0.311**	0.392**	0.216*	0.245**	0.488**	0.390**	-	**0.880****
zy2_gn	-0.034	-0.149	0.049	0.00	0.075	0.464**	0.441**	0.308**	0.405**	0.220*	0.262**	0.471**	0.545**	0.734**	-

Bifur; bifurcation, C. bar; cross bar, Tri C; trifurcation, Tri B; trifurcation, ls-li; mouth width, ch-ch; mouth width, ls-sto; upper vermilium width, sto-li; lower vermilium width, ps1-pi1; right orbital width, ex1-en1; right orbital length, ps2-pi2; left orbital width, ex2-en2; left orbital length, zy1-v; right zygon to vertex; zy2-v; left zygon to vertex; zy1-gn; right zygon to gnathion; zy2-gn; left zygon to gnathion; T; thumb **P < 0.01, * P < 0.05

Table 4.22: Correlations between right minutiae types (category A) with facial angles and ratio (male-up and female-down)

Left T	Bifur	C.bar	Tri C	Tri B	End	APM	NA	NFrA	MCA	NFcA	NMA	UFW/LFW	UFW/UFH	LFH/FH	UFW/LFH
Bifur	-	-0.007	-0.088	0.110*	-0.039	-0.073	0.075	0.034	0.029	0.006	0.00	-0.06	-0.039	-0.022	-0.016
C.bar	0.039	-	-0.032	-0.047	0.317**	-0.062	.110*	0.03	0.055	-0.009	0.01	-0.094	-0.007	-0.043	0.063
Tri C	0.022	-0.022	-	-0.036	-0.037	0.061	0.008	0.031	-0.021	0.013	-0.006	0.019	0.049	0.032	0.016
Tri B	-0.007	-0.03	-0.024	-	-0.053	-0.12*	0.002	-0.063	0.007	-0.045	-0.06	-0.002	0.034	0.078	-0.078
End	0.023	0.05	-0.072	0.159	-	0.055	.287**	-0.14*	0.324**	0.054	0.194**	-0.255**	0.203**	0.134*	0.049
APM	0.073	-0.042	-0.20*	-0.047	-0.057	-	-0.016	-0.026	0.145**	-0.042	0.118*	0.067	0.161**	-0.111*	0.395**
NA	-0.045	-0.147	-0.056	0.049	-0.112	0.241**	-	-.19**	0.291**	0.385**	0.022	-0.818**	0.539**	0.322**	0.167**
NFrA	-0.065	-0.02	-0.069	-0.032	-0.047	-0.116	-0.07	-	-0.40**	-0.32**	-0.127*	0.202**	-0.240**	-0.27**	0.113*
MCA	0.045	0.037	-0.022	0.012	0.024	-0.092	0.077	-0.077	-	0.158**	.668**	-0.279**	0.131**	0.078	0.054
NFcA	0.019	-0.055	0.00	0.196*	0.08	0.053	0.052	-0.42**	-0.104	-	-0.28**	-0.240**	0.205**	0.110*	0.089
NMA	0.083	0.051	-0.008	-0.077	-0.015	-0.20*	0.056	0.092	0.749**	-0.46**	-	-0.161**	0.065	0.153**	-0.160**
UFW/LFW	-0.095	0.024	-0.049	-0.004	0.099	0.068	-0.65**	-0.059	-0.163	0.054	-0.30**	-	-0.317**	-0.38**	0.223**
UFW/UFH	-0.022	-0.107	-0.045	0.037	0.004	0.201*	0.616**	-0.18*	-0.089	0.04	0.045	-0.283**	-	0.788**	0.009
LFH/FH	0.043	-0.095	0.063	0.006	0.035	-0.128	0.423**	-0.106	-0.125	0.014	0.100	-0.411**	0.858**	-	-0.605**
UFW/LFH	-0.107	0.04	-0.168	0.044	-0.059	0.511**	0.058	-0.066	0.117	0.039	-0.124	0.384**	-0.256**	-0.71**	-

Bifur; bifurcation, C. bar; cross bar, Tri C; trifurcation, Tri B; trifurcation,, APM; aperture modified angle, NA; nasion angle; NFrA; naso-frontal angle, MCA; mento-cervical, NFcA; naso-facial angle; NMA; naso-mental angles, UFW/LFW; upper facial width to lower facial width, UFW/UFH; upper facial width to lower facial height, LFH/FH; lower facial height to facial height, UFW/LFH; upper facial width to lower facial height, T; thumb **$p < 0.01$, * $p < 0.05$

4.6 CORRELATIONS BETWEEN THUMBPRINTS RIDGE DENSITY, THICKNESS, PORES, BMI WITH FACIAL PROFILES.

Table 4.23-4.28 showed the correlation ridge density, pore count, BMI with facial linear dimension, angles, and ratio in both sexes. A negative correlation was observed in the ridge density of the three areas (ulna, radial and proximal) and proximal ridgepore count with linear facial dimension, angle, and ratios. Few exceptions were noticed between URC and sto-li (Table 4.24), URC and UFW/LFW (Table 4.25) in themales; for females, between URC with ps1-pi2 and ex1-en1, PRC with sto-li, ex2-en2 (Table 4.27). MCA also correlated with PRC in male and PRPC in female (Table 4.28).

In males BMI correlated with all the linear facial dimensions except with n-sn (Table 4.23), ls-li, ls-sto, sto-li, ps1-pi1, ex1-en1, ex2-en2 (Table 4.24), APM, NFrA, MCA, NFcA, UFW/UFH, UFW/LFW (Table 4.25). Similarly, in females, BMI correlated with facial dimensions, except with en-en, sn-ls (Table 4.23), ch-ch, ps1-pi1, ps2-pi2, ex1-en1 (Table 4.24), NFrA, NFcA (Table 4.68).

Table 4.23: Correlations between right ridge density and BMI with facial dimension (category I) (male-up and female-down)

Right T.	**URC**	**RRC**	**PRC**	**PRPC**	**BMI**	**n-sn**	**sn-gn**	**g-sn**	**en-en**	**al-al**	**zy-zy**	**sn-ls**	**go-go**	**sn-sto**	**sto-gn**
URC	-	0.394**	0.347**	0.143	-0.136**	0.114*	-0.051	0.016	-0.079	-0.033	-0.04	-0.04	-.179**	-0.018	-0.062
RRC	0.086	-	0.184**	0.24	-0.011	-0.057	-0.102	-0.109*	0.003	-.0102*	-0.075	-0.015	0.016	-0.053	-0.105*
PRC	0.215*	0.227*	-	0.332*	-0.097	0.051	-0.016	0.047	-0.172**	0.011	-0.035	0.023	-0.108*	-0.004	-0.023
PRPC	0.049	-0.426	-0.319	-	-0.254	-0.199	-0.255	-0.323*	0.022	-0.243	-0.159	0.075	-0.071	-0.021	-0.322*
BMI	0.072	-0.117	-0.002	-0.251	-	-0.056	0.225**	0.113*	0.122*	0.145**	0.274**	0.104*	0.297**	0.106*	0.230**
n-sn	0.071	-0.066	-0.038	-0.049	-0.049	-	0.219**	0.630**	0.035	0.523**	0.456**	0.025	-0.184**	0.142**	0.194**
sn-gn	-0.055	-0.019	0.112	-0.737*	0.465**	0.009	-	0.703**	0.145**	0.480**	0.514**	0.348**	0.265**	0.659**	0.902**
g-sn	0.158	-0.02	0.044	-0.416	0.398**	0.548**	0.632**	-	0.04	0.655**	0.602**	0.116*	0.006	0.425**	0.654**
en-en	0.096	-0.144	-0.02	-0.426	0.152	0.343**	0.345**	0.496**	-	0.190**	0.352**	0.129*	0.468**	0.154**	0.099
al-al	0.013	-0.083	-0.132	-0.262	0.255**	0.324**	0.249**	0.426**	0.487**	-	0.581**	0.107*	0.056	0.312**	0.431**
zy-zy	0.024	-0.083	0.02	-0.725*	0.464**	0.367**	0.590**	0.709**	0.641**	0.538**	-	0.140**	0.332**	0.324**	0.475**
sn-ls	-0.056	0.065	-0.047	0.364	0.066	0.043	0.189*	0.207*	0.063	0.04	0.096	-	0.134**	0.689**	0.05
go-go	0.064	-0.06	0.053	-0.770*	0.507**	0.134	0.658**	0.651**	0.425**	0.417**	0.802**	0.043	-	0.106*	0.277**
sn-sto	-0.044	0.073	0.043	0.239	0.201*	-0.003	0.592**	0.441**	0.280**	0.174*	0.342**	0.661**	0.284**	-	0.275**
sto-gn	-0.044	-0.061	0.115	-0.790*	0.461**	0.013	0.912**	0.543**	0.277**	0.214*	0.543**	-0.106	0.654**	0.210*	-

URC; ulna ridge count, RRC; radial ridge count PRC; proximal ridge count, PRPC; proximal ridge pore count BMI; body mass index, n-sn; nasal length/ upper facial height, sn-gn; lower facial height, g-sn; special upper height I, en-en; inter ocular distance, al-al; nasal width, zy-zy; upper facial width; sn-ls; philtrum length, go-go; lower facial width, sn-sto; upper lip length, sto-gn; lower lip length, T; thumb **P < 0.01, * P < 0.05

Table 4.24: Correlations between right ridge density and BMI with facial dimension (category II) (male-up and female-down)

Right T.	**URC**	**RRC**	**PRC**	**PRPC**	**BMI**	**ls-li**	**ch-ch**	**ls-sto**	**sto-li**	**ps1_pi1**	**ps2_pi2**	**ex1_en1**	**ex2_en2**	**zy1_gn**	**zy2_gn**
URC	-	0.394**	0.347**	0.143	-0.136**	0.081	-0.01	0.024	0.106*	0.046	0.096	0.078	0.029	0.021	0.001
RRC	0.086	-	0.184**	0.24	-0.011	-0.032	-0.051	-0.05	-0.011	-0.057	-0.103*	-0.027	-0.045	-0.093	-0.088
PRC	0.215*	0.227*	-	0.332*	-0.097	0.068	0.071	-0.023	0.119*	0.06	0.059	0.082	0.055	-0.02	-0.009
PRPC	0.049	-0.426	-0.319	-	-0.254	-0.038	-0.129	-0.14	0.056	-0.109	-0.124	-0.17	-0.215	-0.262	-0.204
BMI	0.072	-0.117	-0.002	-0.251	-	-0.011	0.118*	0.028	-0.038	-0.092	-0.104*	0.03	0.073	0.155**	0.207**
ls-li	0.028	-0.037	0.101	-0.579	0.232**	-	0.433**	0.785**	0.870**	0.324**	0.323**	0.450**	0.476**	0.520**	0.514**
ch-ch	0.004	0.001	-0.085	-0.267	0.146	0.485**	-	0.295**	0.422**	0.380**	0.354**	0.564**	0.562**	0.577**	0.577**
ls-sto	0.003	0.026	0.106	-0.086	0.189*	0.753**	0.326**	-	0.391**	0.246**	0.179**	0.330**	0.351**	0.365**	0.363**
sto-li	0.039	-0.079	0.053	-0.613	0.169*	0.791**	0.422**	0.193*	-	0.282**	0.344**	0.415**	0.429**	0.487**	0.487**
ps1_pi1	0.156	0.018	0.034	-0.255	0.006	0.065	0.175*	0.034	0.065	-	0.703**	0.576**	0.589**	0.445**	0.375**
ps2_pi2	0.126	0.025	0.026	-0.232	0.064	0.028	0.148	-0.085	0.121	0.554**	-	0.527**	0.575**	0.424**	0.400**
ex1_en1	0.109	0.111	-0.011	-0.238	0.09	.187*	0.416**	0.147	0.142	0.393**	0.348**	-	0.863**	0.662**	0.614**
ex2_en2	0.027	0.054	0.037	-0.467	0.209*	.221**	0.445**	0.13	0.209*	0.317**	0.373**	0.588**	-	0.648**	0.646**
zy1_gn	0.092	0.048	0.118	-0.333	0.303**	0.457**	0.395**	0.311**	0.392**	0.216*	0.245**	0.488**	0.390**	-	0.879**
zy2_gn	-0.017	-0.019	0.086	-0.233	0.248**	0.464**	0.441**	0.308**	0.405**	0.220*	0.262**	0.471**	0.545**	0.734**	-

URC; ulna ridge count, RRC; radial ridge count PRC; proximal ridge count, PRPC; proximal ridge pore count BMI; body mass index, ls-li; mouth width, ch-ch; mouth width, ls-sto; upper vermilium width, sto-li; lower vermilium width, ps1-pi1; right orbital width, ex1-en1; right orbital length, ps2-pi2; left orbital width, ex2-en2; left orbital length, zy1-v; right zygon to vertex; zy2-v; left zygon to vertex; zy1-gn; right zygon to gnathion; zy2-gn; left zygon to gnathion, T; thumb
**p < 0.01, * P < 0.05

Table 4.25: Correlation between right ridge density and BMI with facial angles and ratio (male up and female down)

Right T	URC	RRC	PRC	PRPC	BMI	APM	NA	NFrA	MCA	NFcA	NMA	UFW/LFW	UFW/UFH	LFH/FH	UFW/LFH
URC	1	0.394**	0.347**	0.143	-0.136**	-0.011	-0.139**	0.071	-0.043	-0.077	-0.087	0.144**	-0.150**	-0.141**	0.03
RRC	0.086	1	0.184**	0.24	-0.011	0.077	0.099	-0.006	0.03	0.034	-0.001	-0.071	0.016	-0.021	0.053
PRC	0.215*	0.227*	1	0.332*	-0.097	0.029	-0.121*	0.086	-0.052	-0.026	-0.061	0.069	-0.09	-0.063	-0.015
PRPC	0.049	-0.426	-0.319	1	-0.254	0.123	0.156	0.138	0.452**	0.214	0.315*	-0.076	0.094	-0.032	0.186
BMI	0.072	-0.117	-0.002	-0.251	1	-0.026	0.114*	-0.032	0.06	0.037	0.042	-0.079	0.234**	.195**	-0.009
APM	0.169	0.005	-0.136	-0.206	-0.12	1	-0.022	-0.025	0.143**	-0.043	0.119*	0.071	0.165**	-0.110*	0.397**
NA	0.02	-0.043	-0.014	-0.39	0.182*	0.241**	1	-0.19**	0.292**	0.384**	0.022	-0.819**	0.536**	.320**	0.164**
NFrA	0.019	-0.036	0.114	0.409	-0.083	-0.116	-0.07	1	-0.40**	-0.32**	-0.13**	.202**	-0.235**	-0.264**	0.114*
MCA	-0.172	0.036	-0.054	0.043	0.191*	-0.092	0.077	-0.077	1	0.160**	0.668**	-0.279**	0.133**	0.079	0.054
NFcA	0.059	-0.002	-0.031	0.083	-0.151	0.053	0.052	-0.42**	-0.104	1	-0.275**	-0.240**	0.201**	0.105*	0.088
NMA	-0.18*	0.016	-0.078	-0.204	0.423**	-0.198*	0.056	0.092	0.749**	-0.46**	1	-0.161**	0.069	0.157**	-0.159**
UFW/LFW	-0.072	0.013	-0.063	0.536	-0.253**	0.068	-0.652**	-0.059	-0.163	0.054	-0.298**	1	-0.315**	-0.382**	0.225**
UFW/UFH	-0.044	0.009	0.048	-0.431	0.337**	0.201*	0.616**	-0.183*	-0.089	0.04	0.045	-0.283**	1	0.786**	0.01
LFH/FH	-0.079	0.035	0.105	-0.554	0.341**	-0.128	0.423**	-0.106	-0.125	0.014	0.1	-0.411**	0.858**	1	-0.605**
UFW/LFH	0.072	-0.044	-0.138	0.123	-0.181*	0.511**	0.058	-0.066	0.117	0.039	-0.124	0.384**	-0.256**	-0.712**	1

URC; ulna ridge count, RRC; radial ridge count PRC; proximal ridge count, PRPC; proximal ridge pore count BMI; body mass index, APM; aperture modified angle, NA; nasion angle; NFrA; naso-frontal angle, MCA; mento-cervical, NFcA; naso-facial angle; NMA; naso-mental angles, UFW/LFW; upper facial width to lower facial width, UFW/UFH; upper facial width to lower facial height, LFH/FH; lower facial height to facial height, UFW/LFH; upper facial width to lower facial height, T; thumb **P < 0.01, * P < 0.05

Table 4.26: Correlations between left ridge density with facial dimension (category I) (male-up and female-down)

Left thumb	**URC**	**RRC**	**PRC**	**PRPC**	**n-sn**	**sn-gn**	**g-sn**	**en-en**	**al-al**	**zy-zy**	**sn-ls**	**go-go**	**sn-sto**	**sto-gn**
URC	-	0.447**	.258**	0.218	0.001	-0.16**	-0.098	0.01	-0.087	-0.097	-0.078	0.026	-.0108*	-.14**
RRC	0.389**	-	.193**	0.133	-0.049	-0.055	-0.097	-0.03	-0.086	-0.044	0.012	0.061	-0.035	-0.047
PRC	0.078	0.106	-	0.537**	-0.133*	-0.088	-0.09	-0.035	-0.091	-0.099	-0.137*	0.029	-0.126*	-0.04
PRPC	0.319	0.236	-0.469	-	-0.052	0.028	0.025	-0.096	0.082	0.262	-0.023	0.22	0.073	-0.022
n-sn	0.05	0.096	-0.011	0.13	-	0.215**	0.630**	0.036	0.519**	0.453**	0.024	-0.19**	0.137**	0.193**
sn-gn	-0.097	0.012	0.017	0.609	0.009	-	0.703**	0.144**	0.481**	0.515**	0.348**	0.266**	0.660**	0.901**
g-sn	0.041	0.025	-0.01	0.642	0.548**	0.632**	-	0.036	0.653**	0.599**	0.117*	0.004	0.425**	0.655**
en-en	-0.096	0.023	-0.042	0.627	0.343**	0.345**	0.496**	-	0.187**	0.349**	0.129*	0.467**	0.153**	0.098
al-al	0.021	0.032	-0.029	0.905**	0.324**	0.249**	0.426**	0.487**	-	0.579**	0.108*	0.056	0.314**	0.431**
zy-zy	-0.033	-0.021	0.077	0.737	0.367**	0.590**	0.709**	0.641**	.538**	-	0.141**	0.332**	0.326**	0.475**
sn-ls	-0.008	-0.011	-0.048	-0.498	0.043	0.189*	0.207*	0.063	0.04	0.096	-	0.135**	0.688**	0.05
go-go	0.045	-0.024	0.063	0.692	0.134	0.658**	0.651**	0.425**	0.417**	0.802**	0.043	-	0.108*	0.277**
sn-sto	-0.045	0.027	-0.072	-0.233	-0.003	0.592**	0.441**	0.280**	0.174*	0.342**	0.661**	0.284**	-	0.275**
sto-gn	-0.094	0.00	0.059	0.568	0.013	0.912**	0.543**	0.277**	0.214*	0.543**	-0.106	0.654**	0.210*	-

URC; ulna ridge count, RRC; radial ridge count PRC; proximal ridge count, PRPC; proximal ridge pore count BMI; body mass index, n-sn; nasal length/ upper facial height, sn-gn; lower facial height, g-sn; special upper height I, en-en; inter ocular distance, al-al; nasal width, zy-zy; upper facial width; sn-ls; philtrum length, go-go; lower facial width, sn-sto; upper lip length, sto-gn; lower lip length, T; thumb ** $P < 0.01$, * $P < 0.05$

Table 4.27: Correlations between left ridge density with facial dimension (category II) (male-up and female-down)

Left T.	URC	RRC	PRC	PRPC	ls-li	ch-ch	ls-sto	sto-li	ps1_pi1	ps2_pi2	ex1_en1	ex2_en2	zy1_gn	zy2_gn
URC	-	0.447**	0.258**	0.218	-0.056	-0.014	-0.053	-0.038	0.007	0.016	-0.078	-0.04	-0.125*	-0.129*
RRC	0.389**	-	0.193**	0.133	-0.084	-0.042	-0.068	-0.073	-0.08	-0.074	-0.088	-0.053	-0.077	-0.067
PRC	0.078	0.106	-	0.537**	0.037	-0.13*	-0.013	0.055	-0.053	-0.084	-0.104	-0.123*	-0.17**	-0.15**
PRPC	0.319	0.236	-0.469	-	0.188	.368*	0.159	0.135	-0.011	0.141	0.103	0.218	0.127	0.076
ls-li	0.036	0.137	0.138	0.628	-	0.431**	0.786**	0.870**	0.321**	0.321**	0.448**	0.474**	0.518**	0.512**
ch-ch	0.064	0.134	0.05	0.687	.485**	-	0.294**	0.420**	0.381**	0.353**	0.564**	0.561**	0.576**	0.577**
ls-sto	-0.047	0.049	-0.05	0.223	.753**	0.326**	-	0.393**	0.243**	0.180**	0.330**	0.350**	0.365**	0.361**
sto-li	0.1	0.158	0.240*	0.623	.791**	0.422**	0.193*	-	0.280**	0.342**	0.412**	0.427**	0.486**	0.485**
ps1_pi1	0.193*	0.031	0.048	-0.189	0.065	0.175*	0.034	0.065	-	0.706**	0.581**	0.591**	0.445**	0.375**
ps2_pi2	0.059	0.033	0.085	0.681	0.028	0.148	-0.085	0.121	0.554**	-	0.524**	0.574**	0.423**	0.401**
ex1_en1	0.185*	0.074	0.098	0.446	.187*	0.416**	0.147	0.142	0.393**	0.348**	-	0.863**	0.663**	0.616**
ex2_en2	0.03	0.05	0.084	0.864*	.221**	0.445**	0.13	0.209*	0.317**	0.373**	0.588**	-	0.648**	0.647**
zy1_gn	0.05	0.101	0.103	0.314	.457**	0.395**	0.311**	0.392**	0.216*	0.245**	0.488**	0.390**	-	0.880**
zy2_gn	0.057	0.086	0.037	0.312	.464**	0.441**	0.308**	0.405**	0.220*	0.262**	0.471**	0.545**	0.734**	-

URC; ulna ridge count, RRC; radial ridge count PRC; proximal ridge count, PRPC; proximal ridge pore count BMI; body mass index, ls-li; mouth width, ch-ch; mouth width, ls-sto; upper vermilium width, sto-li; lower vermilium width, ps1-pi1; right orbital width, ex1-en1; right orbital length, ps2-pi2; left orbital width, ex2-en2; left orbital length, zy1-v; right zygon to vertex; zy2-v; left zygon to vertex; zy1-gn; right zygon to gnathion; zy2-gn; left zygon to gnathion, T; thumb
**p < 0.01, * p < 0.05

Table 4.28: Correlations between left ridge density with facial angles and ratio (male-up and female-down)

Left T.	URC	RRC	PRC	PRPC	APM	NA	NFrA	MCA	NFcA	NMA	UFW/LFW	UFW/UFH	LFH/FH	UFW/LFH
URC	-	0.447**	0.258**	0.218	0.075	0.088	0.021	0.078	-0.06	0.075	-0.093	-0.065	-0.109*	0.089
RRC	0.389**	-	0.193**	0.133	-0.021	0.1	0.061	0.01	0.017	-0.003	-0.085	0.025	0.00	0.029
PRC	0.078	0.106	-	0.537**	0.078	0.083	0.058	0.113*	0.059	0.07	-0.095	0.082	0.056	0.013
PRPC	0.319	0.236	-0.469	-	0.073	0.06	0.27	-0.395**	-0.382*	-0.361*	-0.023	0.237	0.074	0.168
APM	0.077	-0.003	0.044	0.434	-	-0.016	-0.026	0.145**	-0.042	0.118*	0.067	0.161**	-0.111*	0.395**
NA	0.09	-0.037	0.049	0.397	.241**	-	-0.19**	0.291**	0.385**	0.022	-0.818**	0.539**	0.322**	0.167**
NFrA	-0.052	0.038	-0.069	-.831*	-0.116	-0.07	-	-0.401**	-0.32**	-0.127*	0.202**	-0.240**	-0.27**	0.113*
MCA	-0.01	0.056	-0.062	.814*	-0.092	0.077	-0.077	-	0.158**	0.668**	-0.279**	0.131**	0.078	0.054
NFcA	0.043	-0.018	0.081	-0.218	0.053	0.052	-0.42**	-0.104	-	-0.28**	-0.240**	0.205**	0.110*	0.089
NMA	-0.061	0.005	-0.051	0.702	-0.198*	0.056	0.092	0.749**	-0.46**	-	-0.161**	0.065	0.153**	-0.160**
UFW/LFW	-0.109	0.013	-0.013	-0.321	0.068	-0.65**	-0.059	-0.163	0.054	-0.298**	-	-0.317**	-0.38**	0.223**
UFW/UFH	-0.067	-0.085	0.047	0.37	.201*	0.616**	-.183*	-0.089	0.04	0.045	-0.283**	-	0.788**	0.009
LFH/FH	-0.087	-0.058	0.012	0.268	-0.128	0.423**	-0.106	-0.125	0.014	0.1	-0.411**	0.858**	-	-0.605**
UFW/LFH	0.066	-0.018	0.054	0.156	0.511**	0.058	-0.066	0.117	0.039	-0.124	0.384**	-0.256**	-0.71**	-

URC; ulna ridge count, RRC; radial ridge count PRC; proximal ridge count, PRPC; proximal ridge pore count BMI; body mass index, APM; aperture modified angle, NA; nasion angle; NFrA; naso-frontal angle, MCA; mento-cervical, NFcA; naso-facial angle; NMA; naso-mental angles, UFW/LFW; upper facial width to lower facial width, UFW/UFH, T; thumb **$p < 0.01$, * $p < 0.05$

4.7 RELATIONSHIP OF BMI, FACIAL AND THUMBPRINT PROFILES

The step-wise multiple regression analyses show that go-go was the single best predictor of BMI in both males and females with apercentage contribution of 8.8% and 25%, respectively. However at step four, three variables, UFW/LFW, LFH/FH and ls-li were added in amale with thecontribution of 16%. For females NMA, UFW/UFH, ps2-pi2 were added with thecontribution of 41.2% (Table 4.29).

From Table 4.30, it was observed that in the right thumbprint, RRT was the single best prediction of BMI in amale with thecontribution of 24.4%. In thefemale, enclosure small was the best predictor with thecontribution of 77.4%. For the left thumbprint, only BMI of afemale was predicted with thereturn as single best variable (88%). In the second step, BMI was predicted with return and bifurcation with 98 percentage contribution.

Tables 4.31 and 4.32 showed the potential of thumbprint ridge counts and minutiae in prediction of facial profiles. It was observed that proximal ridge count predicted most of the naso-labial distances whereas the ulnar ridge density predicted the facial ratios and angles. In minutiae trifurcation convergence,ridge endings and cross-bar were observed to be good predictors of the obital distances (Table 4.32).

Table 4.29: Multiple regression for prediction of body mass index from facial dimensions

Sex	Steps & Models	Variables	B	R^2	SEM	F
MALE PARTICIPANTS	**1. BMI**= lower facial width x 0.083 +11.682	(Constant)	11.682	0.088	2.52	36.40*
		go-go	0.083			
	2. BMI= lower facial width x 0.138 + UFW/LFW x 6.02 -1.83	(Constant)	-1.183	0.125	2.47	26.98*
		go-go	0.138			
		UFW/LFW	6.02			
	3. BMI= lower facial width x 0.132 + UFW/LFW x 6.916 + LFH/FH x 12.106 - 8.868	(Constant)	-8.868	0.146	2.44	21.32*
		go-go	0.132			
		UFW/LFW	6.916			
		LFH/FH	12.106			
	4. BMI= lower facial width x 0.148 + UFW/LFW x 8.827+ LFH/FH x 14.001 + mouth height x -0.096 - 11.408	(Constant)	-11.408	0.161	2.42	17.98*
		go-go	0.148			
		UFW/LFW	8.827			
		LFH/FH	14.001			
		ls-li	-0.096			
FEMALE PARTICIPANTS	**1. BMI**= lower facial width x 0.29 -8.967	(Constant)	-8.967	0.257	3.94	46.41*
		go-go	0.29			
	2. BMI= Upper facial width x 0.237+ NMAx 0.104 - 15.752	(Constant)	-15.752	0.335	3.75	33.51*
		go-go	0.237			
		Nasomental Angle (NMA)	0.104			
	3. BMI= lower facial width x 0.193+ NMA x 0.109+UFW/UFH x 3.675 - 21.51	(Constant)	-21.511	0.37	3.66	25.85*
		go-go	0.193			
		Nasomental Angle	0.109			
		UFW/UFH	3.675			
	4. BMI= lower facial width x 0.171+ NMA x 0.137+UFW/UFH x 4.479 + left orbital height x 0.671 - 33.008	(Constant)	-33.008	0.412	3.55	22.97*
		go-go	0.171			
		Nasomental Angle	0.137			
		UFW/UFH	4.479			

* P < 0.05, BMI; body mass index; NMA; naso-mental angles, UFW; upper facial width, UFH; upper facial height, go-go; lower facial width, ls-li; mouth height.

Table 4. 30: Multiple regression for prediction of BMI from thumbprints variables

Digit	Sex	Models	Variables	B	R^2	SEM	F
Right thumb	Male	1. BMI=Radial ridge thickness x 10.519 +12.271	(Constant) Radial ridge thickness	12.271 10.519	0.24	1.86	11.94*
	Female	1. BMI=Enclosure (small) x (-2.82) +22.905	(Constant) Enclosure(small)	22.905 -2.817	0.77	0.88	20.59*
Left thumb	Male	-	-	-	-	-	-
	Female	1. BMI=Return x-2.275 +19.725	(Constant) Return	19.725 -2.275	0.88	0.701	29.85*
		2. BMI=Return x (-2.17) + Bifurcation x -0.36 + 21.017	(Constant) Return Bifurcation	21.017 -2.169 -0.36	0.98	0.33	73.76*

* P < 0.05, BMI; body mass index

Table 4. 31: Step-wise multiple regression for prediction of facial profiles from thumbprint ridge counts

Sex	Thumb	Models	R^2	SEE	F	P
Male	Right	Lower vermilion width= 0.23 (PRC) + 11.54	0.01500	2.51	5.48	0.02
		Special upper face height I= -0.62(RRC) + 97.36	0.0116	9.01	4.19	0.041
		Lower facial width= -1.13(URC) + 109.76	0.0318	9.32	11.73	0.001
		Lower facial width= -1.45(URC) +0.76 (RRC) + 105.12	0.0454	9.27	8.46	<0.001
		Height of lower third of the face= -0.34(RRC) + 45.16	0.0126	4.72	4.54	0.034
		UFW/LFW= 0.01(URC) + 1.10	0.0184	0.02	7.71	0.006
		UFW/LFW=- 0.012(RRC)+ 0.017(URC) +1.19	0.0405	0.02	8.57	<0.001
		UFW/UFH = -0.029 (URC) + 3.01	0.0201	0.30	7.31	0.007
		LFH/FH= -0.0026 (URC) + 0.62	0.0149	0.03	5.40	0.021
Male	Left	Nasal length= -0.58 (PRC) + 49.99	0.02121	5.34	7.00	0.009
		Nasal width= -0.36 (PRC) + 46.37	0.01417	3.99	4.64	0.032
		Philtrum length= -(PRC) + 14.51	0.02316	2.35	7.66	0.006
		Upper lip length= -0.30(PRC) + 26.38	0.01856	0.02	7.13	0.008
		Mouth width= -0.56 (PRC) + 58.89	0.01825	5.49	6.00	0.015
		Lower facial height= -0.70 (URC) + 72.35	0.0233	0.03	8.72	0.003
		Lower facial width= -0.80 (PRC) + 127.04	0.0149	8.71	4.88	0.028
		Height of lower third of the face= -0.48(URC) + 56.55	0.0196	4.87	6.47	0.011
		LFH/FH= -0.0031(URC) + 0.63	0.0182	0.03	6.00	0.015
Female	Right	Special upper face height I= 0.73(URC) + 72.75	0.0356	6.12	4.28	0.041
	Left	Lower vermilion width= 0.28 (PRC) + 10.09	0.05798	1.74	6.65	0.011

URC; ulnar ridge counts, RRC; radial ridge count, PRC; proximal ridge count, LFH; lower facial height, UFH; upper facial height, UFW; upper facial width, FH; facial height.

Table 4. 32: Step-wise multiple regression for prediction of facial profiles from thumbprint ridge counts and minutiae

Sex	Thumb	Models	R^2	SEE	F	P
Male	Right	Left orbital height= -0.12 (RRC) + 13.97	0.0090	0.01	4.13	0.043
		Left orbital height= -0.20 (RRC) + 0.21 (URC) + 12.64	0.0310	0.03	6.73	0.001
		Inter ocular distance = -0.41 (PRC) + 34.38	0.0250	3.48	9.15	0.003
		Nasion angle= -0.99 (URC) + 77.07	0.0190	10.63	7.04	0.008
		Nasion angle= -1.57 (URC) + 1.37 (RRC) +68.73	0.0530	10.45	10.03	<0.001
		Nasal length= (-5.98) x Trifurcate convergence + 44.77	0.0143	5.50	4.67	0.032
		Right orbital height= (0.78)x Crossbar +12.69	0.0097	0.01	4.16	0.042
	Left	Right orbital height= -0.32 (PRC) + 35.11	0.0154	3.45	5.04	0.026
		Nasal length= (-0.45) x Ending + 45.15	0.0634	5.30	22.34	<0.001
		Nasal width = (-0.23)x Endi ng + 43.92	0.0311	3.99	10.60	0.001
		Right orbital height= (-0.10)x Ending + 13.06	0.0350	1.69	11.98	0.001
		Left orbital height = (-0.08) x Ending + 12.96	0.0193	1.76	6.48	0.011
		Right orbital width = (-0.26) x Ending + 33.02	0.0534	3.33	18.63	<0.001
		Left orbital width = (-0.27) x Ending + 32.80	0.0693	3.10	24.57	<0.001
		Left orbital height= -0.34 (PRC) + 34.98	0.0197	3.19	6.48	0.011
Female	Right	Mentocervical angle= -1.08 (URC) + 99.28	0.0461	7.94	5.60	0.02
		Nasomental angle = -1.72 (URC) + 135.62	0.0436	13.07	5.29	0.023
		Left orbital height = (0.85) x ross-bar + 12.50	0.0368	1.47	4.43	0.037
		Right orbital width = (1.57) x Trifurcate convergence + 29.33	0.0429	1.80	5.21	0.024
	Left	Right orbital height= 0.21(URC) + 10.33	0.0458	1.50	5.19	0.025
		Right orbital width = 0.23 (URC) + 26.89	0.0364	1.82	4.08	0.046
		Right orbital width = (-2.57) x Cross-bar + 29.41	0.0491	1.83	5.78	0.018

URC; ulnar ridge counts, RRC; radial ridge count, PRC; proximal ridge count.

CHAPTER FIVE

5.0 DISCUSSION

In the present study, the frequency of the pattern of the left and right thumbprint patterns follow the universal trends, with arches as least, followed by whorls and loop the highest. It was observed that although males tend to have ahigher frequency of three patterns, except for whorl pattern, the association between sex and thumbprint pattern was not significant. This results disagrees with the finding of a previous study, which reported that male Hausas had more abundant whorls and loops than females, while the females had more abundant arches than males (Danborno and Idris, 2007). However, another study of digital dermatoglyphics of two ethnic groups in Nigeria, Yoruba and Igbo documented that Igbo males have fewer whorls and more arches than the females (Igbigbi *et al*., 1994). Similarly, analysis of the fingerprints of the Tibetans shows that the females exhibited a higher frequency of whorl (Tiwari and Chattopadhyay, 1968).

This indicates that there are universal variation and similarities in the patterns of the thumbprints. This can support the importance of the fingerprint pattern as a factor for ethnic differentiation to some extent. It can also be deduced that within the same ethnic group, there may be variation, which may be linked to the potential of the fingerprint as agenetic marker, whereas within the same population, close relatives may tend to have more similar patterns than the distance relatives. However, in this study, despite the variation in the frequency between the sexes, there is no significant association between gender and thumbprint pattern. As a result, the thumbprint patterns are not good in gender discrimination, as such may not be used to discriminate sex in the study population.

Significant differences were observed between the sexes in the ridge density. Females have significantly higher ulna ridge density in the right thumb and significantly lower proximal ridge density in the left thumb. It was earlier reported that ridge density varies according to sex, age, and population origin (Gutiérrez-Redomero *et al*., 2011). Sex differences were reported in fingerprint ridge in different populations, including Spanish Caucasians (Gutie´rrez-Redomero *et al*., 2008), Spanish populations (Martın and Portabales 1986; Arrieta *et al*., 1987; Arrieta *et al*., 1990), Sardinian population (Floris, 1975), Egyptian (Eshak *et al*., 2013), Chinese and Malaysian (Nayak *et al*., 2010), some Indian populations (Nayak *et al*., 2010), including South Indian population (Nithin *et al*., 2011), Indo-Mauritian population (Agnihotri *et al*., 2012), Central Indian (Marathi) population (Kapoor and Badiye, 2015) among others. In almost all the populations, females have agreater number of ridges than males, but a different result was observed in the present study where the males had higher ridge compared to the females. This finding was also supported by previous studies evaluating total fingerprint ridge counts in Africans, reported Kenyans and Tanzanian males have more ridges than their females counterparts (Igbigbi and Msamati, 2005). These variations in fingerprint ridge densities further confirm the presence of population-specific differences. Furthermore, there was enough evidence regarding intra- and inter-population difference in densities using different methods. It can be suggested that higher ridge density in males (present study), absence of sexual dimorphism (Gutiérrez-Redomero *et al.,* 2008), and the higher ridge density in females (Gutiérrez-Redomero *et al.,* 2011; Ahmed and Osman, 2016; Rivaldería *et al.,* 2016), documented in the proximal area of the digit is an indication of higher population variability in this region compared to other areas (ulnar and radial) of the digit.

To explain the variation in ridge density between sexes, it was observed that females tend to have finer epidermal ridges than their male counterparts (Moore, 1989). The males were also reported to have coarser ridges than the females by approximately 10% (Kralık and Novotny, 2003). In addition to this observation, it was also noted that the difference between the finger ridge density in males and females in a given area may be linked to sexual dimorphism in body proportions, in which on the average males are larger than females. Therefore, the same numbers of ridges are accommodated amongst the females in a small surface area and a higher density noted amongst females (Krishna *et al*., 2010; Kapoor and Badiye, 2015). However, this varies with theregion of the prints, and the lower ridge density in females in the proximal area may be linked to the orientation of the ridges, while in the proximal area the ridges are more of horizontal compared to another regions of the finger.

It was suggested that the radial and ulnar sides of the fingers seem to respond to different developmental instructions, which would be enough motivation for the use of radial and ulnar counts as separate variables (Jantz and Owsley, 1977). This may further answer a question on why on the same fingerprints a variation, being a sex wise or population wise, will occur in one area and absent in another area. It was also noted that the similarities and differences reported between different sex and population (example Spanish and Mataco-Mataguayo) represents the existence of population-variable genetic factors that influence the ontogenetic development of ridges (Gutiérrez-Redomero *et al*., 2011). A confounding variable such as age needs should be considered when making acomparison between sex and population. This is because ridge density (RD) which is permanent after formation

decrease with age and, at all ages, ridge density was higher on the distal (radial and ulnar) area, followed by the proximal sides. Females were found to have higher ridge density than males when older than 12 years, but not when younger in the Mataco-Mataguayo population (Gutiérrez-Redomero *et al*., 2011). This is proportionate with increases in the body composition and proportion, which differ among the population and more critical on gender at aspecific age.

Ridge thickness is one of the variables that have aninverse relation with ridge density. A higher ridge density indicates lower ridge thickness. In the present study, the right thumbprint ridge thickness were significantly higher in ulna area in the males. However, in radial ridge thickness, the females recorded significantly higher mean value. In the left thumbprints, females have significantly higher ridge thickness in both radial and proximal areas. It has been shown that the ridge breadth in the radial area is greater in males than in females in the Spanish and Mataco-Mataguayo populations, respectively; likewise, for the ulnar and proximal areas (Gutiérrez-Redomero *et al*., 2011). Analyses of epidermal ridge breadth of human fingerprints on ceramic artifacts show that mean epidermal ridge breadth can be used as an indicator of age (from birth to maturity) and sex of the artifact maker in adulthood, with 9% greater in males than in females (Kralik and Novotny, 2003). This is in line with earlier work by Ohler and Cummins (1942) which found that the ridges of females were 10.2% finer than the ridges of males. However, these sex difference is age sensitive, as age advances the sexual dimorphism is more pronounced and significant (Loesch and Czyzewska, 1972; Gutiérrez-Redomero *et al*., 2011). The only similarities with our present finding are on the ulna area, but for other areas (radial and proximal), the findings

contradict. This indicated that there is population variability with respect to an area that has thicker ridge thickness in females compared to males. This may be due to differences in the genetic make-up and developmental processes that exist among the different populations. Lifestyle and nutritional access of different populations may contribute to some extent.For example, the exposure to manual work and type of food eaten may influence the coarseness of the ridges in various populations. For instance, a study conducted by Gutiérrez-Redomero *et al*. (2011) observed that Spanish males have athicker ridge in the radial area by 10% compared to females, but for Mataco-Mataguayo population the difference was just by 7%. This finding may indicate the possibility of further decrease and even reversal of the characteristics as seen in this study. Hence, the thickness may be of potential value in population differentiation.

Considering pores association with athumbprint, proximal area pores of the right thumb showed a significant sexual dimorphism with higher pore count in females and such differences were absent in left thumbprints. It was reported that sexual dimorphism exists in pore count, but as the age advances, no significant difference was noted in the number of pores in both the sexes (Nagesh and Bathwell, 2011). The difference observed may be linked to differences in ridge count between males and females, as the higher the proximal ridge count the higher the pore counts in those areas. The mean number of pores were not compared with other populations as method adopted in pore counts are different. In most of the population, the pore counts were carried out per centimeter of a ridge. In the present study, a defined area (proximal) was used. This is to give achance of a number of ridges to

be included in order to eliminate the effect that may be conferred by the differences in the ridge thickness of the finger within or outside an area.

In this study gender specificity of the fingerprint ridge density was observed. In previous study prior probability analyses it was reported that in central India population, the statistical analysis of likelihood ratio and odds ratio show that ridge density ≤12 ridges/25 mm^2 and ≤ 13 ridges/25 $mm^2$are more likely to be males and females respectively. Posterior probability using Baye's theorem shows that a fingerprint with ridge density ≤ 10 ridges/ 25 mm^2 is of male origin and ≤ 16 ridges/25 mm^2 will be more indicative of females (Kapoor and Badiye, 2015). This results showed little variation from ridge density in Chinese and Malaysian population (Nayak *et al*., 2010). Among Egyptian population, females had more ridge count (right: female > 21.0 ≥ male, left: female > 21.2 ≥ male, and higher ridge density (right: female >1.35 ≥ male, left: female > 1.5 ≥male) (Eshak *et al*., 2013).

The above studies were based on equal prior probabilities P(C) =P (C0). However, if the prior probabilities are in favor of male subjects P(C) = 0.7 and P (C0) = 0.3, due to more involvement of male in crime than the female in the real world, the threshold increased (Gutie´rrez-Redomero *et al*., 2008). It may be problematic if the usual sex involvement is violated or not properly determined, hence, leading to result with little accuracy and application. It is also important to know that some areas of the fingerprints are not sexually dimorphic, therefore, their involvement in sex discrimination may be of little significant.

Step-wise (forward) binary logistic regression (BLR) was used in the present study to discriminate sexes. It was shown that right ulna ridge count was the single best variable to discriminate sex. The accuracy of the prediction increases when the radial ridge thickness was added to the equation. For the left thumbprints, the proximal ridge thickness discriminates sex when the proximal ridge count was added to the equation. It was also observed that the ulna ride count and proximal ridge thickness using ROC curve analyses were the best discriminators with ahigher area under the curve in the right and left thumbprints respectively.

One of the pillars of dactyloscopy identification is the used of fingerprint minutiae. Its study and analyses have long been considered as the scientific bases that determine the process of individualization in personal identification using fingerprints (Ashbaugh, 1999; Vanderkolk, 2001).The variability of the minutiae among the different areas of the finger remains the motivating factor for the various study of its variability across thedifferent population. Regarding thumbprint minutiae, significance differences in the mean value of the right thumbprint minutiae between males and females was observed. The females have higher mean value in break and bridges whereas the males have higher values in ridge end, enclosure (small and big) and opposite bifurcation. In the left thumbprints, the significance was noticed only in abifurcation, cross-bar, end, enclosure (small), convergence, return, point/dot between the ridges. Only return and convergence have higher mean value in the female. Sex wise analysed in the previous study show that ridge ending, convergences, bifurcations, and enclosures were more frequent in female (Gutiérrez-Redomero *et al*., 2007). In alater study by the same author, it was confirmed that males presented a

statistically significant greater number of minutiae than the females. The differences between the sexes were significant for ridge endings, bifurcations, breaks, and crossbars, which were on average found less often in the females (Gutiérrez-Redomero *et al*., 2011). This is in line with the present finding with respect to the type of minutiae that exhibited sexual dimorphism. However, thereverse is the case with respect to sexdominance in the minutiae types. This may highlight to us there could be a mechanism that operates in determining which minutiae type should be more common in a particular sex. Another possible extrapolation is that gene controlling, this may not be associated with sex chromosome, rather may be in association with the autosomal gene, which expression may vary between sexes in different populations. That is, in a given population it may well express in male while in another population the expression may be in favor of females.

Contrarily, differences in means for males and females were not found for Japanese in the earlier study, although among the German subjects counts were higher for males. Further study on Japanese population (twins) shows the level of sexual dimorphism in mean minutiae counts (Okajima, 1967). This may portray the importance of methodology with respect to the analyses of the minutiae. It was reported that significant different existed in Japan population, after more robust methodology was used. Hence, the need for universally accepted methodology for analyses of the minutiae for better and accurate comparison between individuals and populations at large.

Considering sexual dimorphism, the current study advanced a little to find the minutiae that best discriminates the sex. It was observed that not all the variables that exhibited sexual dimorphism are good discriminators. In the right, all the sexually dimorphic minutiae are included in the equation with a break as asingle best discriminator. For the left, some sexually dimorphic traits were excluded from the equation with ridge end as asingle best predictor. The analyses of predicted probabilities of BLR for the variables that contributed best to the prediction shows that only break and bridges were the best predictors for right, and return and convergence for the left. This indicated that contribution of some variables to the discrimination are not substantial as the discrimination may well occur in their absences.

In the field of facial anthropometry, Farkas *et al.* (2005) had compiled the single most comprehensive survey of ethnic groups from multiple regions around the world. Despite this comprehensive approach, the global range of variation for each facial measurements was not well documented (Fang *et al*., 2011). Among twenty-one facial linear dimensions, only inter-ocular distance, upper facial width, philtrum length, lower vermilion width, right orbital length and left orbital width toshow no sexual dimorphism. This is in line with findings of orther researchers (Olotu *et al*., 2009; Karaca *et al*., 2012). It was reported that certain facial features show no sexual dimorphism, while in others the differences are in favour of the females. Upper and lower lip height were reportedly higher in the females; while in upper face width, eye-fissure width, forehead height I and II, no sexual dimorphism exists (Karaca *et al*., 2012). For other variables such as facial and nasal length, Igbo males tend to have significantly higher mean values (Olotu *et al*., 2009). African-

American males also have ashorter nasal length (nasion-subnasale), wider alar width (alare-alare), compared to the Caucasians (Porter, 2004). It can be suggested that certain facial regions have less proportionate developmental processes with other body parts as such they are less influenced by intrinsic factors of the body.

In another context similar to this study, males tend to have significantly higher mean value in most of the facial variables (Zhuang *et al*., 2004; Sforza *et al*., 2010). This may indicate that females in general have smaller faces than males (Zhuang *et al*., 2004). This also supports the fact that the males have an averagely larger body size and proportion compared to the females, which is also applicable to the face.

With regards to different population, in the Turkish adult,the mean value of the nasal height in males was similar to Chinese (Aung *et al*., 2000) and American Caucasian mean values (Farkas, 1994). For females, the mean nose length was the same as in Malaysian Indian (Ngeow and Aljunid, 2009). But it is longer than the nasal length of American Caucasian females (Farkas, 1994). The nasal width of the present study was less than that of other studies but very close to that of American Caucasians. In another comparison, African-Americans have significantly different face length and lip length from Caucasian, Hispanics, and the other race/ethnic groups. Moreover, face width of African-Americans, Hispanics, and others was all significantly different from the Caucasian group. All of which are different from the Hausas of this study. Inter-ethnic variability among the facial variable from a review comprising 27 different ethnics from five principal racial groups (European, African, East Asian, South Asian, Native American) showed that the lowest

level of variation in the mid face widths, zygion-zygion,andexocanthion-exocanthion along with the lower face width gonion-gonion. The fore-head height was observed to have thegreatest degree of variation, which recorded the higher degree of variability than any measurement except endocanthion-endocanthion (en-en) (Van de Graaff, 2001; Fang *et al*., 2011).

It is well known that face is one of the first line of identity of the different populations due to the significantly marked difference between them. It can therefore be deduced that the variation usually affects the vertical distances more than the horizontal. This may also correlates with differences in the vertical body proportion compared to the horizontal ones. It is also a fact that environmental factor such as ultra-violet radiation stimulates the synthesis of the vitamin D, a precursor in the process of bone formation. As such individual leaving in an area with higher exposure to ultra-violet rays (such as areas near theequator) will tend to be longer (vertical body proportion) and probably higher vertical facial proportion. Other factors such as nutrition, adaption to the environment, genetic make-up may be responsible for inter-ethnic variation and sexual dimorphism.

In addition to sexual dimorphism, certain facial trait discriminates sex more than the others. In the present study nasal length was found to be the best discriminator of sex. Other variables that added to the discrimination power were special upper facial height I, nasal width, lower facial width, mouth width, right orbital width. For predicted probabilities of BLR for the variables that contributed best to the prediction showed that only nasal length, right orbital width and left orbital width were good predictors. This is just additional

support on the contribution of the vertical facial dimensions in discrimination. For this study, it was observed that the vertical facial dimensions have better predictive probability in sex discrimination compared to horizontal facial dimensions.

Analysis of the soft tissue facial profile provides information on the morphology of the profile and its relationship with the underlying dentoskeletal tissues (Fernández-Riveiro *et al*., 2003) as the extensive evaluation of angular relationship are essential in soft tissue profiling since not all facial traits directly follow the underlying dento-skeletal profile (Subtenly, 1959). Therefore, for proper evaluation, dento-skelatal profile of Hausa population, their facial angles were analyzed. It was observed that only nasion and aperture modified angle did not show significance gender differences. In all the remaining angles, females have higher value with theexception of nasofacial angle. However, in the variable with significance gender differences only naso-mental angle show some level of sex discrimination. The ROC curve analyses show that nasomental angles discrimination power is not a matter of chance.

It was reported that in the north Indian, European, Croatian Caucasian, Turkish and Urhobos (Nigeria) populations (Fernández-Riveiro *et al*., 2003; Anic´-Miloševic *et al*., 2008; Malkoc *et al*., 2009; Oghenemavwe *et al*., 2010; Reddy *et al*., 2011) the mean value of naso-frontal angle was higher in females as seen in our study. But lower than obtained in our population with the exception of Turkish and North Indian population (female only). Epker (1992) in a study on frontal and lateral facial views of Caucasians found no gender

differences in this angle. The reason for the variation of this angle may be attributed to glabella which is more prominent in other populations (Oghenemavwe *et al*., 2010). In addition, the degree of nasal inclination may be another possible factor of the variations.

With regard to mento-cervical angle, the north Indian, Urhobos of Nigeria, and Turkish populations (Malkoc *et al*., 2009; Oghenemavwe *et al*., 2010; Reddy *et al.,* 2011) have higher mean value compared to present study and males have higher mean value, which is contraryto this study. However, the mean value of this study is higher compared to European Caucasian (Fernández-Riveiro *et al*., 2003). It was suggested that the males have more prominent chin compared to females leading to higher mean value (Reddy *et al*., 2011). It means that among the Hausa population, females have amore prominent chin. It may also be suggested that the differences in protrusion of the mandible may contribute to the gender variation. For thenasomental angle, ethnic variation was also observed between the different populations with no sexual dimorphism (Anic´-Miloševic *et al*., 2008; Reddy *et al*., 2011) and significantly higher mean in males (Oghenemavwe *et al*., 2010) which are in disagreement with the findings of this study. In the nasofacial angle, the north Indian adult population (Reddy *et al*., 2011) and Croatian-Caucasian population (Anic´-Miloševic *et al*., 2008) females have higher mean value as observed in this study. The reverse is the case in adult Urhobos of Nigeria (Oghenemavwe *et al*., 2010). The simple explanation to this can be due to the fact that one of the sexes has less protruded nose. The prominence of glabella and chin may be additional contributors to the variation.

In frontal profile, the angle related to the aesthetically pleasant facial profile includes facial aperture modified angle and nasion angle. The study among Brazilians and Caucasians, showed that the facial aperture modified angle was lower in the aesthetically unpleasant group and higher in the pleasant group. Lower values for this angle may be linked to longer and thinner face (Morosini *et al*., 2012).

The nasion angle, the pleasant group has intermediate values between aesthetically unpleasant and accepted groups, similarly indicating a tendency for horizontal facial growth for individuals composing pleasant group (Ackerman and Proffit, 1997). However, differences were observed between males and females. Although female faces may be considered to have aesthetically pleasant facial profile. This, therefore, may also project a variation in the underlying dentoskeletal profile of the different populations.

Asymmetry indicates a failure of an identical development on both sides of the body of an individual (Kusuma *et al*., 2001). But sometimes, are acquired in the life of individuals. In the present study, significant differences occurred in different types asymmetric indices; signed, absolute and composited asymmetry with regards to thedifferent type of minutiae. However, in other populations, (Japanese and German), absence of asymmetry in minutia count was reported (Okajima 1966) confirmed later by the same author on Japanese population (Okajima 1967). This population variation may be linked to themethod used in assessing the minutiae. For ridge density, significant sex differences in asymmetric indices with females recording higher mean value. In the previous study, the sexual dimorphism was not significant in both mean signed and mean absolute asymmetry (AA), except in the

fourth finger for mean AA (Kusuma *et al*., 2001). It was also evident that males had a higher ridge breadth than females, which was associated with a higher rightward signed asymmetry in the ridge counts (Karlik and Novotny, 2003). This led to thesuggestion that sex chromosomes may be a factor influencing ridge counts as it has been reported to affect the size of the cells (Bosco *et al*., 2001).

Another reason may be linked to nature of the manual work males are subjected compared to the females. It was documented that the part of the body subjected to use may grow alittle bit better than the other parts. Since the majority of the participants were right-handed, then a coarser ridge may be associated with theright thumb with higher ridge count in left and higher mean sighed asymmetry in females.

With respect to facial dimension, a significant sexual dimorphism was observed only in zygion-gnathion facial dimension in both absolute asymmetry and composited asymmetry. This may suggest less disturbance in the asymmetry in the facial profile compared to the thumbprint profiles. Differences in thesubjectivity of left and right differed significantly between face and digit (which contains the fingerprints). To better explain the basis of the sex differences, it was reported that the tendency of the males to be asymmetrical may be linked to the increase in the environmental stresses. It might be that environmental stress, such as poor living conditions, may affect males more strongly than females because in many species, including human males tend to be more vulnerable compared to females (Ozener and Fink, 2010). This may explained in the findings in the present study.

Fluctuating asymmetry (FA), which was considered as small random deviations (around a mean of zero) from perfect bilateral symmetry, may not be fully observed in some bilateral trait. Criteria were put in place to assess the possibility of a bilateral trait to exhibit fluctuating asymmetry. Using one sample t - test only, bifurcation exhibits directional asymmetry in males and six different minutiae in females. For ridge density, all the variables in both sexes exhibit FA.

Further evaluation of FA normality test shows that both minutiae and ridge density show significant skewness and kurtosis in the signed asymmetry. This supported the idea that in a trait with tendency of side (right or left) dominance, the asymmetry type is most likely to be thedirectional type. Most studies (Cummins *et al*., 1994; Mundorff *et al*., 2014; Kapoor and Badiye, 2015) established the existence of asymmetry in fingerprints. According to Cummins *et al*. (1994), the ridges of the right are coarser than the left hand. Thus, for the same area, the right hand would have fewer ridges than the left hand. Moreover, it was evident that ridge density in both sexes among Spanish Caucasians population, where the ridge density is greater in the areas of the left hand, thus showing finer ridges than in the right hand. It was also observed that mean ridge breadth is greater for right fingers than for left fingers, (Mundorff, *et al*., 2014). The explanation was reported in a study of central Indian population report, where the ridge density in the thumb fail to show a significant level of asymmetry (Kapoor and Badiye, 2015).

Using the facial dimension, one sample t - test revealed the level of FA in facial dimension. The normality test, however, shows that orbital length and zygon to gnathion poor indicator of FA. Split-plot ANOVA for assessment of repeatability asymmetry shows no significant interaction between differences in the repeatability of measurement and signed asymmetry in the facial variables. This indicated that the variables are not agood indicator of FA. Ercan *et al*. (2008) reported the number of significantly asymmetric linear distances between the two halves of the face. Based on thetype of asymmetry, 12 of 35 traits (34%) in male faces had the properties of FA. The remaining 66% of traits exhibited DA. For female faces, seven of 35 traits (20%) had the properties of FA. The remaining trait exhibit DA (Simmons *et al*., 2004). This may show that most of the facial trait exhibited thedirectional type of asymmetry. The absence of facial trait that exhibited FA in the present study may be linked to the fewer number of the variables.

Founder effect or genetic drift as one of the evolutionary forces resulting in reproductive isolation and reduced genetic diversity may have led to the ethnic variation in the facial appearance. It was also suggested that through sexual selection, individuals with anattractive facial profile may have been more likely to reproduce and pass on such traits to subsequent generations (Buggio *et al*., 2012). In this study, both males and females had no occurrence of classical canon of facial proportion. In other studies (Farkas, 1994; Jayaratne *et al*., 2012), facial canon is present although with low frequency. For example, in Southern Chinese faces, Jayaratne *et al*. (2012) reported thefrequency of 19% of orbito-nasal canon and 8.7% in naso–oral canon. This has provided bases for thedistinction of different ethnic groups.

Study on different ethnic groups established that the frequency of valid canons was greatly surpassed by their variations. This indicates that other than the canon the variationcan be used to compare different populations and sexes within the same population. In this study,there is no significant association between gender and facial proportion. However, females have higher percentages of the variant of the canon, compared to the males in all classes of the canon. In Hong Kong Chinese population, the variant in the orbital canon with a wider intercanthal distance was found to be 100%, remarkably higher than the 51.5% observed in North American Caucasians (Farkas *et al*., 1985). The frequency of this variant in Singapore Chinese (Le *et al*., 2002) was similar to Southern Chinese (Jayaratne *et al*., 2012). A relatively narrowmouth with awide-nose variant of the naso-oral canon was common among all the East Asian ethnic groups and the African-Americans (Farkas *et al*., 2000). By extension, the variant of the canon may also provide some insightinto population differences.

In contrast to present findings, significant gender differences in relation to the frequency of the orbito-nasal canon variant was found among theSouthern Chinese population. (Jayaratne *et al*., 2012). In addition, thecomparison between males and females African-American shows the significant different level of occurrence of canon between sexes. In African-American males, only canon, I and VI have been established with the prevalence of 2.8% and 11.9% respectively. The rest of the canons (II to IX) indicate the dominance of one variant with more than 95%. In canon VII, the two variants share the proportion somehow equally (Poter, 2004). This indicates a case gender differences in the occurrence of the cannon. Moreover, it can be suggested that ethnic variation exists with respect to

different classes of canon. Therefore, the existence of harmonious face is still valid in the world, but with sex bias.

From a biological point of view, it is well established that the phenotype of the biological organism is uniquely determined by the interaction of a specific genotype and a specific environment (Jain *et al*., 2002). Physical appearances of faces and fingerprints are also part of an individual's phenotype. In dermatoglyphics studies, like facial anthropometry, the maximum generic difference between fingerprints has been reported among individuals of different populations. Unrelated persons of the same population have very little generic similarity in their fingerprints, parents and their child have some generic similarity as they share half of the genes, siblings have more similarity and the maximum genetic similarity is observed in the identical twins, which have the closest genetic relationship (Cummins and Midlo, 1961; Ozkaya and Sagiroglu, 2008d; Sagiroglu and Ozkaya, 2009b).

The present study shows no significant association between the thumbprint pattern of the right and left thumb with both vertical and horizontal facial proportion in male participants. Similarly in females, no significant association between the horizontal facial proportion and thumbprints. This provides information on the differences in the proportional increases of theface and thumbprints. It may be suggested that factors such as avolar pad, boundary effect among others that determine the pattern of the fingerprints (Kunken and Newell, 2005), are not controlled by the same mechanism that determines the facial proportion. Further analyses of thumbprint profile shows that different types of thumbprint profile

(minutiae) correlate with facial linear dimensions,angle, and ratio in both sexes and sides of the thumb. A study analysing the similarities in fingerprint minutiae patterns in identical twin fingers shows that the fingerprints of identical twins highly correlated as observed in their facial anthropometry. In addition to this high minutiae correlation, other profiles of fingerprints such as ridge count, ridge width, ridge separation and ridge depth were also found to be significantly correlated in identical twins (Jain *et al*., 2002). Several studies examine the correlation among faces and fingerprints of the identical twins (Bodmer and McKie, 1994; Costello, 1999; Jain *et al*., 2001; Jain *et al*., 2002; Kong and Zhang, 2006; Youssif *et al*., 2007). The unique identity exhibited by theindividual facial expression is also exhibited by fingerprints. Therefore, the two traits may share the same intrinsic factor that controls them, hence, leading to some significance degree of correlation.

The relationship between the biometric features of faces and fingerprints are well established. This led to proposed novel approaches for generating several components of the facial traits from fingerprints. This includes the face borders, face contours, including face border and ears, inner face parts including eyes, nose, and mouth (Ozkaya and Sagiroglu, 2008c; Sagiroglu and Ozkaya, 2009b). The establishment of arelationship between these variables may be considered as one of the criteria for personal identification. This may also have potential in narrowing down the investigation process, and thus provides useful clues to anexpert in the process of personal identification.

One of the aims of anthropometry is to provide an alternative or indirect method of estimation of body variables. However, such aim is normally achieved when the variable in question have asignificant correlation. In the present study, the correlation between BMI and facial anthropometry is in agreement with studies reported for other populations. For example, a previous study established a relationship between three facial features: width to height ratio, perimeter to area ratio, and cheek to jaw width ratio with BMI. Sex-wise analyses showed that these three facial features were significantly related to BMI in males, while theonly width to height ratio and cheek to jaw ratio were significantly related to BMI in females (Coetzee *et al*. 2010). This indicateds gender variation in the correlation as observed in the present study, where variables such as upper facial width, mouth width, upper vermilion border, lower vermilion border, UFW/UFH, UFW/LFW among others correlate with BMI in females only. Correlations between four additional facial features and BMI were also reported among young Korean population (Pham *et al*., 2011). This findings indicated the potential of some facial features in the prediction of BMI.

The stepwise multiple regression analyses to estimate BMI shows that go-go was the single best predictor of BMI in both males and females among Hausa population. However, UFW/LFW, LFH/FH and mouth height were also other important predictors. In a study conducted using automated approaches, the cheek bone to jaw width, width to upper facial height ratio, perimeter to area ratio, eye size, lower face to face height ratio, face width to lower face height ratio, and eyebrow height were used to predict BMI (Wen and Guo, 2013). This shows th econsistency of some variables across the population. One advantage of predicting BMI from the facial feature is that the approach is simple and non-invasive.

The conventional methods of measuring individual's height and weight in order to compute his or her BMI may be avoided. This can be suggested as an alternative approach for some practical uses, such as in on-line photos or surveillance videos of faces, where it is impossible to use traditional method of obtaining BMI (Coetzee *et al*., 2009;Coetzee *et al*., 2010; Pham *et al*., 2011, Wen and Guo, 2013). Itis, therefore, possible to compute the BMI of an individual using direct or indirect anthropometry. To explore the importance of other variables in this context, fingerprints which correlates with facial anthropometry were also used to predict the BMI. It was observed that radial ridge thickness and enclosure small were the single best prediction of BMI in males and females, respectively. For the left thumbprint, only BMI of females was predicted with return and bifurcation minutiae type. This study helped in providing more parameters for the estimation of BMI.

The prediction potential of thumbprint profiles observed in the present study may be supported by the fact that both fingerprints and facial morphology have strong influence of genetic factors expression. Some genes that were reported to express in low to medium levels in the skin were found to play a key role in the determination of facial features (Claes et al., 2014; Ho et al., 2016). Therefore, it was suggested that the two traits (fingerprint and facial features) may share the same intrinsic factor that controls them, hence, leading to some significant degree of correlation between the two variables.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

It can be concluded that the frequency of the pattern of the left and right thumbprint patterns follow the universal trends. Fingerprint pattern has little influence on the ridge density, thickness, and minutiae. The ridge thickness have an inverse relation with ridge density. It was noted that on the same thumbprint, different regions have different potentials in terms of gender discrimination. Vertical facial linear dimensions were the best discriminators of sex compared with horizontal. Not all the variables that are sexual dimorphic discriminate sexes. Some discrimination power of certain variables are by chance; as further analyses (using ROC curve) eliminated them. Facial angles are not good discriminators of sex, but have more potentials in distinguishing of different ethnic groups. Leftward direction symmetry was found in both males and females, indicating more ridge count on the left side. The asymmetry in both thumbprint and facial dimension indicates directional types, although affinity to FA is more in facial than thumbprint profiles. Canon was not found in Hausa population and the variant was not sexually dimorphic. No significant association was observed between the thumbprint pattern of the right and left thumb with facial proportion. Fingerprint profile correlated either positively or negatively with facial profiles, indicating some degree of linear relationship between the two profiles. BMI can be predicted from facial and thumbprint profiles and the best prediction was observed in facial profile. The relationship between thumbprint and the facial profile was established to be linear.

6.2. RECOMMENDATIONS

i. The data generated for facial and thumbprint profile should be used as baseline data or reference values among the Hausa population of Kano State, Nigeria.

ii. Different ethnic groups and larger sample sizes should be used in order to explore more on the relationship between facial and thumbprint profiles.

iii. A similar study on other Hausa populations or different ethnic groups should be carried out in order to establish a good reference data for Hausas of other original seven Hausa States such as Daura, Zaria, Sokoto among others.

iv. Study with a large number of paired facial dimension should be done to see the possibility of establishing the fluctuating asymmetry among the Hausa population.

v. Studies can also be done with age groups outside 18-25 to observe whether the relation improves as age changes.

6.3 CONTRIBUTION TO KNOWLEDGE

i. A baseline data was obtained for the Hausa ethnic group of Kano State, Nigeria in their thumbprint and facial profiles. Based on the data, models were developed for discriminating sex in this population. For example using ridge ending, the accuracy of sex discrimination is 65.4% [Sex= (0.274x ridge ending) -0.878] and when more minutiae are added, the accuracy rised to 75.6% [Sex= (0.156 x bifurcation) + (0.23xEnd) + (0.479 x enclosure small) + (-0.282 x convergence) +(-23.91 x return) + (0.506 x point between ridges) -1.377]. Similarly, for facial dimension upper facial height [Sex = -0.274 (upper facial height) + 11.926] have 76.2 % accuracy for sex discrimination, and when more variables are added to the mode [sex =-0.56

(upper facial height) + 0.297 (special upper height I) + 0.307(nasal width) + (-0.134) (lower facial width)+ 0.264(mouth width)+ (-0.592) (orbital width) -4.249] the accuracy of 91.1 % was achieved.

ii. This study also highlighted the pattern of FA in this population. Using three different types of FA indices(signed, absolute and composite), sexual dimorphism in FA was established. In most of variables considered in this study, females were shown to have higher mean asymmetry. In both sexes, most of the variables, using signed asymmetry indices, showed leftward asymmetry rather than the rightward asymmetry

iii. This population is proven to have differences with other populations using neoclassical facial proportion canon. In the entire population, no occurrence of neoclassical canon of facial proportions. However, the variant of the canon found to be typical characteristics of the Hausas of Kano State, Nigeria.

iv. The relationship between thumbprints and facial profiles was determined among the Hausa population. This provides an insight of possibility of generating facial characteristics from thumbprint features among Hausas of Kano State Nigeria.

v. An alternative means of prediction of BMI from thumbprint and facial profile among Hausas was achieved. In this context, some of the modelsfor BMI prediction developed were; BMI= 0.29 (lower facial width) - 8.967, BMI= lower facial width x0.171+ naso mental angles x 0.137+UFW/UFH x 4.479 + left orbital width x 0.671 -33.008 (for females), BMI= lower facial width x 0.083 +11.68, 4. BMI= lower facial width x0.148 + UFW/LFW x 8.827+ LFH/FH x 14.001 + mouth width x -0.096 - 11.408 (for males).

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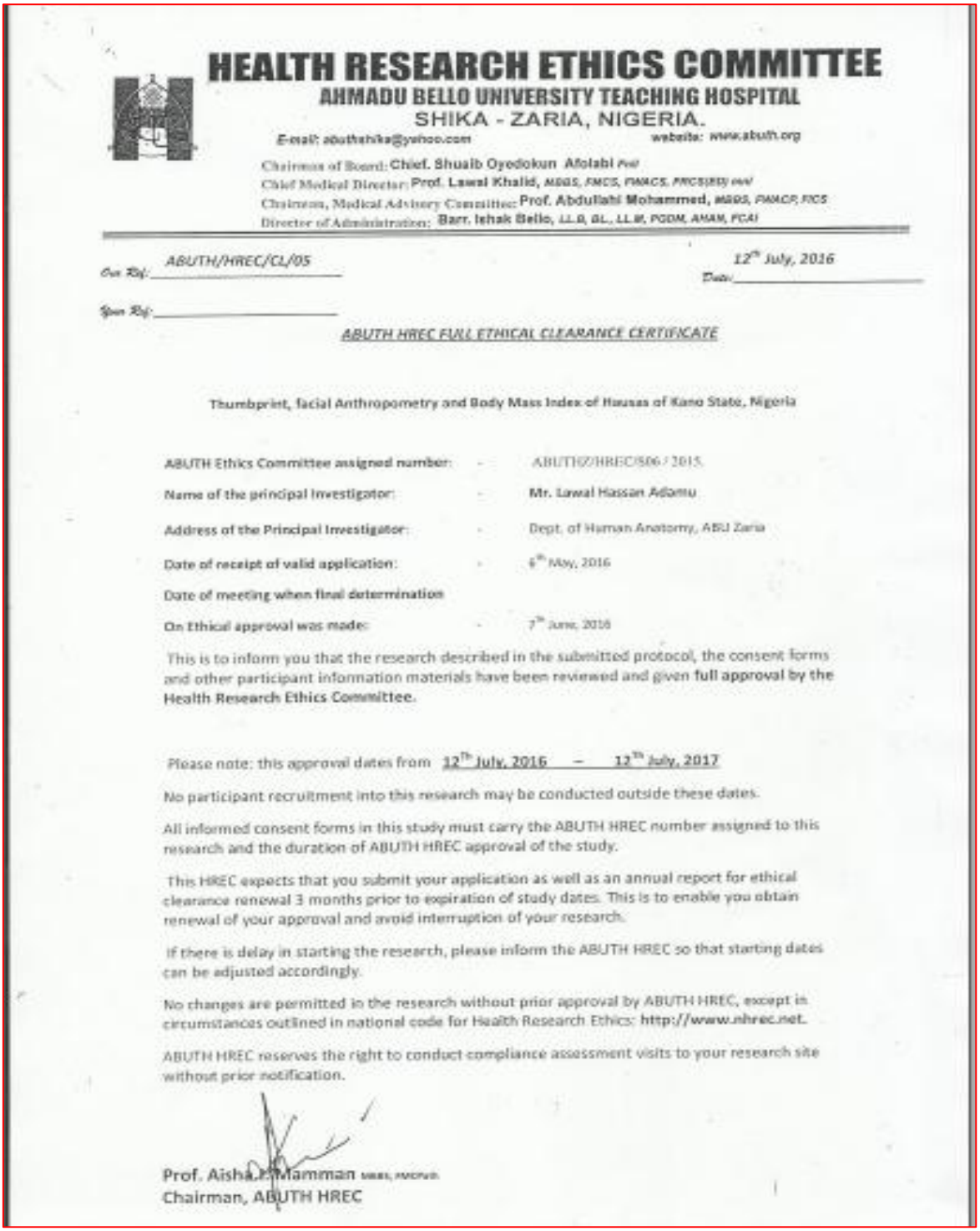
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APPENDIX I: ETHICAL CLEARANCES



HEALTH RESEARCH ETHICS COMMITTEE
AHMADU BELLO UNIVERSITY TEACHING HOSPITAL
SHIKA - ZARIA, NIGERIA.

E-mail: abuthshika@yahoo.com website: www.abuth.org

Chairman of Board: Chief. Shuaib Oyedokun Afolabi *Prof*
Chief Medical Director: Prof. Lawal Khalid, *MBBS, FMCS, FWACS, FRCS(Ed) (Hon)*
Chairman, Medical Advisory Committee: Prof. Abdullahi Mohammed, *MBBS, FWACP, FICS*
Director of Administration: Barr. Ishak Bello, *LL.B, BL., LL.M, PGDM, AMAN, FCAI*

Our Ref: ABUTH/HREC/CL/05 Date: 12th July, 2016

Your Ref:

ABUTH HREC FULL ETHICAL CLEARANCE CERTIFICATE

Thumbprint, facial Anthropometry and Body Mass Index of Hausas of Kano State, Nigeria

ABUTH Ethics Committee assigned number:	-	ABUTH/HREC/506 / 2015
Name of the principal Investigator:	-	Mr. Lawal Hassan Adamu
Address of the Principal Investigator:	-	Dept. of Human Anatomy, ABU Zaria
Date of receipt of valid application:	-	6th May, 2016
Date of meeting when final determination		
On Ethical approval was made:	-	7th June, 2016

This is to inform you that the research described in the submitted protocol, the consent forms and other participant information materials have been reviewed and given **full approval by the Health Research Ethics Committee.**

Please note: this approval dates from 12th July, 2016 – 12th July, 2017

No participant recruitment into this research may be conducted outside these dates.

All informed consent forms in this study must carry the ABUTH HREC number assigned to this research and the duration of ABUTH HREC approval of the study.

This HREC expects that you submit your application as well as an annual report for ethical clearance renewal 3 months prior to expiration of study dates. This is to enable you obtain renewal of your approval and avoid interruption of your research.

If there is delay in starting the research, please inform the ABUTH HREC so that starting dates can be adjusted accordingly.

No changes are permitted in the research without prior approval by ABUTH HREC, except in circumstances outlined in national code for Health Research Ethics: http://www.nhrec.net.

ABUTH HREC reserves the right to conduct compliance assessment visits to your research site without prior notification.

Prof. Aisha I. Mamman *MBBS, FWCPath*
Chairman, ABUTH HREC

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Adamu Lawan Hassan
Department of Anatomy,
Bayero University Kano.

PROVISIONAL ETHICAL CLEARANCE

Sequel to your request to conduct a research titled "**Study of Thumbprint, Facial Anthropometry and Body Mass Index of Hausas in Nigeria**". In the light of the above, I am mandated to convey provisional clearance to you to proceed on your study based on the following conditions.

i. That the consent of all participants must be obtained by filling-in consent form.
ii. That you should liaise with the Management of the facility for appropriate guidance.
iii. That any publication related to the study should be brought to the knowledge of the Ethical Committee for approval.
iv. That a copy of your finding should be submitted for documentation, record and final approval, please.

Best wishes.

MAIMUNAH KHALID A.
ASSISTANT SECRETARY II
FOR: EXECUTIVE SECRETARY

CC:

The Chief Medical Director,
MMSH
Kano.
Above is for your information and noting, please.

MAIMUNAH KHALID A.
ASSISTANT SECRETARY II
FOR: EXECUTIVE SECRETARY

APPENDIX II: CONSENT FORMS

CONSENT TO PARTICIPATE IN OUR RESEARCH; Study of Thumbprint, Facial Anthropometry and Body Mass Index of Hausa Ethnic Group in Nigeria

You are asked to participate in a research study to be conducted by ADAMU, Lawan Hassan from the Department of Human Anatomy, Faculty of Medicine, ABU, Zaria,

If you have any question or concerns about the research, please feel free to contact ADAMU, Lawan Hassan Department of Human Anatomy, Faculty of Medicine, ABU, Zaria, 08138300444, alhassan.ana@buk.edu.ng

1. **Purpose of the Study:** The Study of Thumbprint, Facial Anthropometry and Body Mass Index of Hausas in Nigeria
2. **Procedures:** The data collection will involve collecting information with regard to bio data, here the participant will be ask to provide some information relevant to his bio data. This can be done in less than 1minute. In the second phase of the study a picture of face (frontal and lateral view) and thumbprint (left and right), then body variables height and weight, these can be achieved within 3-5 minutes
3. **Potential Risk and Discomfort:** There is no associated risk with this procedure and the only discomfort may be the time you will sacrifice while taken the measurement.
4. **Potential Benefits to Participant and/or to society:** This research may be of potential benefit to the participant and/or society in the following ways;

(a) Opportunity to know your thumbprint and facial profiles and other important parameters such as height, weight, body mass index among others.

(b) The participant may have an opportunity to come in contact with the equipment used in the study as well as gaining knowledge about the names and uses of such equipment

(c) Measuring the head and facial variables provides room for establishment of indicator and diagnostic criteria as well as information potentially usable in clinical practice and art. Moreover, the facial proportion are known to have been used to create the so called ‘facial canon’, which is an ideal of beauty.

5. **Payment for Participation:** Incentive and refreshment will not be offered to the participant after participation

6. **Confidentiality:** Every effort will be made to ensure confidentiality of any identify information that is obtained in connection with this study. The variables and information collected will only be used for the aims and objectives of the study as well as scientific publications. I assure you that your pictures and other information will be kept in strict confidence.
7. **Participation and Withdrawal:** You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may exercise the option of removing your data from the study. You may also refuse to answer any questions you don't want to answer and still remain in the study. The researcher may withdraw you from this research if circumstances arise that warrant doing so.
8. **Right of Research Participants:** You may withdraw you consent at any time and discontinuous participation without penalty. You are waiving any legal claims, right or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through Committee on ethics from Ahmadu Bello University Teaching Hospital, Zaria. If you have questions regarding your right as a research participant contact; Committee on ethics,Ahmadu Bello University Teaching Hospital, Zaria, Tel;
9. **Signature of Research Participants/ Legal Representative:** I have read the information provided for the study titled. Study of Thumbprint, Facial Anthropometry and Body Mass Index of Hausas in Nigeria, as describe herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form

_____ _____

Name of the participant Name of the witness

_____ _____

Signature of the participant /date Signature of the witness /date

CONSENT FORM FOR USE OF PHOTOGRAPHS

Photographer/ Investigator/ Researcher

I, Adamu Lawan Hassan of Department of Human Anatomy, Faculty of Medicine, Ahmadu Bello University Zaria would like to take your photograph for purposes of my thesis dissertation titled; *Study of Thumbprint, Facial Anthropometry and Body Mass Index of Hausas in Nigeria.* These images may be sent out to the journals or any scientific community for publications.

Person(s) in photograph

I agree to allow Adamu Lawan Hassan to take photographs of me and grant permission for these to be used by him to promote scientific knowledge through publications, press articles, and websites, exclusively for non-profit-making purposes.

Name:.....ALKAIRU HASSAN.....

Date of Birth....15-5-1991.....

Contact email address or telephone number: .....08065075676.....

Signed: .....

Date: .....7-2-2016.....

I also agree to my name being published in any associated publicity if required.

☑ Yes ☐ No

I/We will not use the images taken, or any other information you provide, for any other purpose other than stated earlier.

APPENDIX III: QUESTIONNAIRE

STUDY OF THUMBPRINT, FACIAL ANTHROPOMETRY AND BODY MASS INDEX OF HAUSA ETHNIC GROUP IN NIGERIA

Bio Data								
					Tribes			
ID	State	Sex	DoB (D/M/Y)	Location of birth	Father	Grandfather	Mothers	Grandmother

Body Anthropometry					
Variables	Values	Variables	Values	Variables	Values
Height (cm)		Weight (kg)		BMI (kg/m^2)	
Muscle mass (%)		Visceral fat (%)		Metabolic rate (Kcal)	

Thumbprints Pattern Classification		
Side	Right	Left
Pattern types		

Right thumbprints: minutiae count intside the circle														
Edng	Bifur	Converg	Frag	Pt o dot	Break	Enclsre	Overlap	xbar	Bridge	Opp. Bifur	Y o M	Dock	Retrn	Othr

Left thumbprints: minutiae count inside the circle														
Edng	Bifur	Converg	Frag	Pt o dot	Break	Enclsre	Overlap	xbar	Bridge	Opp. Bifur	Y o M	Dock	Retrn	Othr

Ridge Density Anthropometry				
Ridge density		Radial side	Ulnar side	Lower side
Measurements	Right			
	Left			

Ridge Thickness Anthropometry						
Ridge thickness	**Right**			**Left**		
	Ulna side	Radial side	Proximal side	Ulna side	Radial side	Proximal side
Length of line (LL)						
No. of ridge/LL						
Measurements						

Pores Counting		
Number of Pores	Right	Left

Facial Anthropometry: **Lateral Angles**				
Angles	Nasofrontal	Mentocervical	Nasofacial	Nasomental
Values				
Frontal Angles				
Angles	Facial symmetry	Gonion	facial aperture modified	Nasion
Values				

	Right	Left
	Proximal side	Proximal side
Counts		

SN	Unpaiired facial dimension	Value (mm)	SN	Unpaiired facial dimension	Value (mm)
1	Special head height (v-en)		11	Upper facial width (zy- zy)	
2	Special face height (en-gn)		12	Philtrum length (sn- ls)	
3	Forehead height II (tr-n)		13	Lower facial width (go- go)	
4	Nose length (n-sn)		14	Upper lip length (sn- sto)	
5	Lower face height (sn-gn)		15	Height of lower third of the face (sto- gn)	
4	Height of calva (v-tr)				
7	Forehead height I (tr-g)		16	Mouth height (ls- li)	
8	Special upper face height I (g-sn)		17	Mouth width (ch-ch)	
9	Inter ocular distance (en-en)		18	Upper vermilion width (ls-sto)	
10	Nasal width (al-al)		19	Lower vermilion width (sto-li)	

		Right	Left		
SN	Paiired facial dimension	Value (mm)	Value (mm)	Ratios	Value
1	Orbital width (ps- pi)			UFW/LFW	
2	Orbital length (ex-en)			UFW/UFH	
3	Zygon to vertex (zy- v)			LFH/FH	
4	Zygon to gnathion (zy- gn)			UFW/LFH	

Nine neoclassical canon of facial proportion and their variations					
Classes	Description	Freqency	Classes	Description	Freqency
Class I and it's variation	v-en = en-gn		Class V and it's variation	en-en = al-al	
	v-en > en-gn			en-en > al-al	
	v-en < en-gn			en-en < al-al	
Class II and it's variation	tr-n=n-sn=sn-gn		Class VI and it's variation	en-en=ex-ex	
	n-sn < sn-gn			en-en > ex-ex	
	tr-n > n-sn			en-en < ex-ex	
	tr-n < sn-gn		Class VII and it's variation	ch-ch= 1.5 (al-al)	
	tr-n > sn-gn			ch-ch > 1.5 (al-al)	
Class III and it's variation	v-tr=tr-g=g-sn=sn-gn			ch-ch < 1.5 (al-al)	
	v-tr < tr-g		Class VIII and it's variation	al-al = 0.25 (zy-zy)	
	v-tr < g-sn			al-al > 0.25 (zy-zy)	
	v-tr < sn-gn			al-al < 0.25 (zy-zy)	
	v-tr > tr-g				
	tr-g > g-sn				
	tr-g < sn-gn				
	g-sn < sn-gn				

APPEXDIX IV: LIST OF PUBLICATIONS AND CONFERENCE PAPERS FROM THE THESIS

A: Journal Articles

i. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. (2016). Sex discrimination using ridge density and thickness among hausa ethnic groups of kano state, nigeria, *Australian Journal for Forensic Sciences, 1-18* http://dx.doi.org/10.1080/00450618.2016.1264477.**(PUBLISHED)**

ii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. (2017). Sex variation in thumbprint minutiae among Hausa lineage. *Journal of Anatomical Sciences, 8(1); 39-47.* **(PUBLISHED)**

iii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. (2017). Evaluation of facial proportion and their association with thumbprint pattern among Hausa ethnic group. *Journal of Anthropology, 2017, Article ID 9571470, 11 pages https://doi.org/10.1155/2017/9571470.* **(PUBLISHED)**

iv. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. (2016) Sex determination using facial linear dimensions and angles among Hausa population of Kano State, Nigeria. *Egyptian Journal of Forensic Sciences.* 6: 459–467. DOI: 10.1016/j.ejfs.2016.11.006. **(PUBLISHED)**

v. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. (2016). Prediction of Body Mass Index from Thumbprint. *Bayero Journal of Biomedical Sciences, 1(1): 69-77.* **(PUBLISHED)**

vi. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Sex differences in facial asymmetry indices among Hausa ethnic group of Nigeria. *Annals of Bio-anthropology,* 4: 105-110. **(PUBLISHED)**

vii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Prediction of nasolabial distance using thumbprints ridge density among hausa population of Nigeria. *Arab Journal of Forensic Sciences and Medicine*. **(ACCEPTED)**

viii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Relationship of orbital dimensions and facial angles with thumbprints ridge count among Hausa ethnic group of Nigeria *Journal of Experimental and Clinical Anatomy.* **(ACCEPTED)**

ix. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Evaluation of Asymmetry Using Thumbprint Minutiae of Hausa Population of Kano State, Nigeria. *Bayero Journal of Pure and Applied Sciences*. **(ACCEPTED)**

x. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Prediction of Facial Distances Using Thumbprint Ridge Minutiae among Hausa Ethnic Group in Nigeria, *Journal of Post-graduate Students (Maiden Edition).* **(ACCEPTED)**

xi. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Prediction of facial height, width and ratio from thumbprints ridge count and its possible applications. *Journal of Forensic Sciences and Medicine.* **(UNDER REVIEW)**

xii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Prediction of body mass index from facial profile among Hausa ethnic group of Nigeria. *Tropical Journal of Medical Research.* **(UNDER REVIEW)**

xiii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Sexual dimorphism in ridge density and thickness asymmetry among Hausa Ethnic Group of Nigeria. Nigerian Journal of Experimental and Clinical Biosciences. **(UNDER REVIEW)**

B: Confernce Presentation

i. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G.. Prediction of facial distances using thumbprint ridge minutiae among Hausa ethnic group in Nigeria, ABU SPGS conference (maiden edition), 2016. Held between 23-24 November, 2016.

ii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Prediction of body mass index from thumbprint profiles among Hausa population. 2nd International Annual Scientific Conference Held at Faculty of Sciences North-West University, Kano, Nigeria. between 6-9 November, 2016 (2nd NWUIC 2016).

iii. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Prediction of body mass index from facial anthropometry in Hausa population. Anatomical society of Nigeria (ASN) conference, Ekiti State University (Ekiti, 2016).

iv. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Sex discrimination using ridge density and thickness among Hausa ethnic groups of Kano State, Nigeria. Ekiti State University (Ekiti, 2016).

v. Adamu, L. H., Ojo, S. A., Danborno, B., Adebisi, S. S. and Taura M. G. Sex Prediction of sex using facial anthropometry among Hausa ethnic population. Ekiti State University (Ekiti, 2016).