UNIVERSITY OF GHANA

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SCANNING ELECTRON MICROSCOPY (SEM) OF SCALP HAIRS OF PERSONS WITH AND WITHOUT ALBINISM

BY

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DECLARATION BY THE CANDIDATE

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere. In addition, materials of the scholars that have been used have either been cited in text or in the reference list.

Candidate's Signature: ………………………… Date …………………

(Abigail Owusua Yeboah)

DECLARATION BY SUPERVISORS

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Ghana.

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DEDICATION

This work is dedicated to my parents Dr Julius Yeboah and Mrs Priscilla Karle Yeboah.

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LIST OF ABBREVIATIONS

PWA – Persons with Albinism

PWA – Persons without Albinism

SEM – Scanning electron microscope

TEM – Transmission electron microscope

HSD – Hair shaft diameter

MSC – Mean scale count

ISM – Interval between scale margins

DNA – Deoxyribonucleic acid

mtDNA – mitochondrial deoxyribonucleic acid

GAPA – Ghana Association of Persons with Albinism

OCA – Oculocutaneous Albinism

CHS – Chediak Higashi syndrome

HPS – Hermansky Pudlak syndrome

FHONDA – Foveal hypoplasia, optic nerve decussation defects and anterior segment dysgenesis syndrome

SPF – Sun protective factor

EDS – Electron Dispersive X-ray Spectroscopy

CMC – Cell Membrane complex

MATP – Membrane associated transport protein

TYRP1 – Tyrosinase related protein 1

WNT – Wingless Int-1

BMP – Bone Morphogenic protein

IGF – Insulin growth factor

HGF – Hepatic growth factor

VEGF – Vascular endothelial growth factor

ACTH – Adrenocorticotropic hormone

PTHrP – Parathyroid hormone related protein

ETG – Ethyl glucuronide

18- MEA – 18- methyl eicosanoic acid

ABSTRACT

Introduction: Scalp hairs are more likely to be shed and lend themselves for examination as identification tool. Identification of hair is very complex and important procedure in forensic investigation. Despite advances in biometric and molecular identification of individuals, hair examination continues to play a key role in screening suspects and zeroing on the species of mammals or race of humans (in cases of badly dismembered or co-mingled body parts in mass disasters). This study assessed topo-morphological features of scalp hair using the higher magnification of scanning electron microscope (SEM) which offered more detailed characteristics than previous light microscopy hair research in Ghana. The study sought to determine whether oculocutaneous albinism is associated with alteration(s) in the SEM features of hairs.

Aim: The aim of the study is to determine the morphological profile of hairs of Ghanaians with Albinism and compare with age-matched persons without albinism for anthropological and forensic use.

Methodology: Three hundred scalp hair samples were obtained consenting 30 Persons with albinism (PWA) and 30 persons without albinism (PWO). Fifteen study participants were male and fifteen were female among PWA and PWO. Hairs were obtained by standard pull-method from five conventional regions of the scalp namely; frontal, vertex, occipital, right and left temporal. Standard procedures were followed to examine hair samples in a scanning electron microscope (PHENOMWORLD24VDC/ 12.5Amp. Max, Netherlands. The microscope generated Electron Dispersive X-Ray Spectrum (EDS) data on hair samples which were also analysed. Quantitative characteristics such as shaft diameter, scale count and interval between scales were statistically compared. Images captured in the SEM of hairs shafts and roots were assessed for qualitative features including scale patterns, configuration of margins, proximity of scales and the type of root.

Results: There was a significant difference between the mean weight percentages of Boron ($p<0.0001$) in hairs from PWA and PWO**.** In the five regions of the scalp studied Carbon, Oxygen and Nitrogen had the highest weight percentages in hairs in order of decreasing precedence for both PWA and PWO. Hair shaft diameter was highest in the right temporal and left temporal regions of the scalp of male PWA and Male PWO respectively. In female PWA and PWO who had natural styled hair, the hair shaft diameter was highest in the frontal and right temporal regions of the scalp respectively. In both females PWA and PWO with permed hair, the highest shaft diameters were found in the vertex of the scalp. The most predominant scale pattern in the proximal shaft and distal shaft of the hair for both groups were regular pattern and irregular pattern respectively. Smooth margins were in higher proportions in the proximal shaft of the scalp hairs while rippled margins were in higher proportions in the distal shaft of scalp hairs for both groups.

Conclusion: Albinism is not concurrent with altered morphological structure of hairs but boron was higher in hairs from PWA than PWO. Protective creams used by PWA to prevent cutaneous damage by solar UV radiation are known to contain boron and may account for this difference.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Hairs contribute to the overall appearance (Trüeb, 2005) and looks of a person and it plays an important part in human contacts as well as interactions (Knapp *et al*., 2014). An important feature of physical appearance with major social and psychological impact on the lives of humans is the scalp hair. The human scalp frames the face since the same face can make different impressions due to different hairstyles (Choe and Ko, 2005). Hair is an important tool that has effect on the charm of a person. In society today, everyone has an opinion of what is termed as beauty, and human females of African descent famously exert a lot of effort to keep their scalp hair styled (Essel *et al*., 2019). There is enormous anecdotal support for the assertion that the value of human hair should not be underestimated in social and emotional terms (Grimalt, 2001). The physical feature of the hair lends itself to easy modification by alteration of colour, shape, or length. In the world of cosmetics, the interest of specified hairdo to realise excellence drives numerous customers (Cruz *et al*., 2016).

Hairs are special to and differentiate mammals from other vertebrates such as birds, reptiles, amphibians and fishes. Kalmoni *et al*., 2019 and Buffoli *et al*., 2014 cited Noback, 1951 that hair is exclusive to mammals and gave them the name “hair animals”. A defining feature common to all mammals is the hair (Amman *et al*., 2002) and its organic structure is known (Schweitzer, 2011). In mammals, hair is a characteristic attribute and apart from the lips, palms and sole of the feet, glans penis, and clitoris, hairs grow in every skin of mammals. However, humans have relatively less dense body hair cover compared to other primates (Randall, 2007). The lack of hair of humans is attributed to the decrease in body hair structure so that hair without colour almost covers numerous areas. Humans have therefore been characterized as ‘naked apes’ (Randall, 2007).

The naked eye appearance of scalp hair shows different characteristics according to race. Hairs have generally been characterized into three racial groups namely: Caucasoid (European origin), Mongoloid (Asian origin) and Negroid (African origin) (Franbourg *et al*., 2003; Duggins and Trotter, 1951). However, De La Mettrie *et al*. (2007) echoed the widespread belief of oversimplification by the three racial categories of hairs and proposed three easily measurable variables to classify hairs found worldwide into 8 main coherent types. The latter workers were able to show differences between scalp hairs of Ghanaian and South African Negroids. It is notable also, that artificial alteration of scalp hair in current years have posed a challenge to their identification and hence hairs on other parts of the body have become useful in determining the age, sex, ancestry and race (Aboagye *et al*., 2014).

Recognisable proof of hair gives a lot of information in the fields of epidemiology, ecology, criminology, archaeology as well as forensic investigations. Hair contains several biological and chemicals substances that can be identified and measured making samples a good biomaterial in physical anthropology and forensic sciences (Chang *et al.*, 2005). After hair formation, the basic chemical composition of hair is not affected by changes in the blood chemistry or exposure to chemicals (Daniel *et al*., 2004). Owing to this, hair samples are often used for autopsy toxicology which includes drug detection, personal identification and forensic genetic identification of relatives (Lebedeva *et al*., 2000). According to Wilson *et al*. (2007), unlike bone and teeth, the hair shaft does not experience post-keratinization biogenic change. They are usually human tissues examined in bioarchaeology.

In addition to the benefits of studying recent hair, the scientific study of ancient hairs can give proofs significant to speak to questions about the past (Bonnichsen *et al*., 2001). Hairs found in archaeological interments are a distinctive resource for capturing a snapshot of life (Chang *et al*., 2005), and the morphology of hair such as scale pattern, medulla, cross-section and colour patterns have provided substantial information on species present at these places (Brothwell and Grime, 2003). Olden mammalian hairs also make available understanding of a site's function, the nature of the environment, species evolution, and the relation between people and animals in the past (Davis *et al*., 2007). Antique human and animal hair can be an essential data source for understanding palaeobiology, palaeoecology and palaeoanthropology (Bonnichsen *et al*., 2001), but unfortunately, it is seldom conserved in the fossil record.

The method of analysing evidence from a crime scene can be done by forensic hair analysis. This can be done by examining the shaft of the hair, with the medulla, cortex and cuticle using different microscopes. For hair samples to be analysed properly, they must be collected according to the accepted protocol (Chatterjee, 2012). Hair can easily be transferred from one individual to another. It clings to furniture, clothes and carpets and can last for years without decomposition. Its uniqueness makes it important trace evidence at crime scenes (Collier, 2004). Hair evidence unless destroyed by fire, or degraded by strong acids or alkaline can have their integrity contained over a long period than any other tissue type. Hairs can survive adverse environmental conditions because they are covered by a resistant external layer, the cuticle which protects the hair fibre (Masters and Kennedy, 2003; Owen, 2000). Different microscopes being used for the analysis of hair brings out the colour and detail of the hair specimen and allows scientists who are in the field of forensics to analyse hair pieces side by side (Benner Jr. and Levin, 2005).

According to Weitzel (1998), once hair samples are retrieved from a crime scene, forensic scientists have to determine first whether the hair is from a human being, an animal or fibre. If the hair is that of a human, it may be for a victim or a suspect which may help for identification.

In the late 1800s, investigators realized the importance of hair analysis as trace evidence in criminal investigations. Hairs found at a crime scene in 1847 were used in the investigation of the murder case of the Duchesse de Praeslin in Paris. A classic 1883 text on forensic science, *The Principles and Practice of Medical Jurisprudence* by Alfred Swaine Taylor and Thomas Stevenson, covers a chapter on using hair in forensic investigations. It comprises drawings of human hairs under magnification. The various parts of human hair are identified. The book also references cases in which hair was used as evidence in England. In 1910, a broad study of hair titled *Le Poil de l'Homme et des Animaux (The Hair of Man and Animals)* was published by the French forensic scientists Victor Balthazard and Marcelle Lambert. This text includes numerous microscopic studies of hairs from most animals.

The use of the comparison microscope to do a side-by-side analysis of hairs collected from a crime scene and hairs from a suspect or victim first occurred in 1934 by Dr Sydney Smith. This method of comparison helped solve the murder of an eight-year-old girl. Further advances in hair analysis continued throughout the 20th century as technological advances allowed for comparison of hairs through chemical methods. Today, hair analysis includes neutron activation analysis and DNA fingerprinting and is considered a standard tool in trace evidence analysis.

At crime scenes, the presence of trace evidence is as a result of physical exchanges between the perpetrator, the victim and even the surrounding within which the crime occurred (Owen, 2000). A fundamental principle governs the phenomenon of exchange evidence which is known as the "Locards Principle of Exchange". This principle states that "every contact leaves a trace"

(Robertson and Grieve, 1999). In modern forensics, this principle has served as a foundation and also helped in solving crimes (Fido *et al*., 2003). In this case, hairs provide information which serves as a link between the crime scene, perpetrator and/or the victim. Used this way, hair examination can also help in exonerating a particular suspect.

In human hair studies, current methods of analysis rely on comparisons of either hair morphology by microscopic examination or nuclear and mitochondrial DNA analysis (Goodpaster *et al*., 2003). Microscopic examination of the morphological characteristics of human hairs indicates the shape, colour, thickness, race, body area (e.g. scalp, pubic, axillary, facial, limbs, chest) and method of removal (e.g. shed naturally or removed forcibly) (Chen and Bhushan, 2005; Goodpaster *et al*., 2003; Benner *et al*., 2003). Analysis of hair has limitations and hair alone cannot help in the identification of victims or suspects. Hair analysis with DNA evidence can help in stating emphatically that a specific hair sample belongs to a particular individual. Hair evidence of an individual when analysed can match the hair of another individual but this limitation does not dispute the fact that forensic analysis of hair is one of the most important tools available in investigating a crime (Araújo *et al*., 2010).

Colour is an important distinguishing feature of hair, but albinos have a varying degree of loss of hair colour. Albinism which is also known as Achromasia, achromatosis or achromia is a rare, non-contagious genetically inherited condition that results from the reduction and absence of the pigment melanin. It occurs in both genders regardless of ethnicity (Newman, 2018). It results from mutations in the genes involved in the biosynthesis of melanin. The most common cause is the interruption in the functioning of the enzyme Tyrosinase. Depending on the specific genes mutated albinism can be split into oculocutaneous (OCA), X-linked ocular, Hermasky-Pudlak syndrome (HPS) and Chediak- Higashi syndrome (CHS) (Newman, 2018; Witkop, 1987).

Oculocutaneous albinism (OCA) is a genetically inherited autosomal recessive condition and OCA2, tyrosine-positive albinism, is the most prevalent type found throughout Africa. The condition results in a lack of pigmentation in the hair, skin and eyes, causing some vulnerability to exposure to bright light. Due to the absence of melanin, persons with albinism are predisposed to the dangerous effects of ultraviolet exposure (Hong *et al*., 2006). The physical features that are usually apparent are the absence of colour in the hair, skin and iris, lighter than normal skin colour and hair, patchy, missing skin colour.

Pigmentation of hair in mammals is due to melanin (Ortonne and Giuseppe, 1993). The pigmentation of hair follicles follows series of events identical to those in the epidermis. Hair colour is based on the pigment content in the shaft of the hair. The colour of hair, skin and eyes in mammals depends on the quality, quantity and distribution of the pigment melanin (Ito and Wakamatsu, 2003). The colour variants of hairs including spotting and albinism are as a result of melanocyte activity and can be determined by the action of multiple genes, some of which operate through the milieu in which the pigment cell resides, other seem to act intercellularly to control the type of melanogenesis (Ortonne and Giuseppe, 1993). In skin and hair colours, differences are principally genetically determined. This is due to the variation in the amount type and packaging of melanin polymers produced melanocytes secreted in keratinocytes. Genes determining the number of rare Mendelian disorders of pigmentation such as Albinism has been identified (Rees, 2003).

Most of the studies done on mammalian hairs have been done utilizing plastic impressions of cuticular scales and direct observations of whole mounts (Kalmoni *et al*., 2019; Essel *et al*., 2019; Aboagye *et al*., 2014). Others have also used the transmission electron microscope (TEM)

(Morioka, 2009). The optical light microscope provides a poor topographic review of the features of hair. The TEM offers an improved resolution but it is affected sometimes by spherical aberration resulting in imperfect images. The Scanning electron microscope (SEM) however have been used by previous investigators successfully to detect the surface structure and scale patterns of the cuticle (Backwell *et al*., 2009; Sahajpal *et al*., 2009; Chang *et al*., 2005). The SEM permits direct observation at high magnification allowing imaging specimen with high levels of detail (Teerink, 2003). The SEM technique is fast and relatively simple. It also shows unique three-D information (Van den Broeck *et al*., 2001).

Energy Dispersive X-Ray Spectroscopy (EDS) is used to measure the elemental components of a sample. The spectroscopy depends on the investigation of the sample through interactions between matter and electromagnetic radiation, analyzing x-rays emitted by the matter in response to being hit charged particles. The EDS spectroscopy gives the percentage of elements in molecular composition; both organic and inorganic (Mujeed and Zafar, 2017).

1.2 Problem Statement

According to Lavker *et al*. (2003), some countries have data on morphological features of hairs, which gives them adequate knowledge for forensic identification of hair. There is scarce information on hair identification in Ghana, which may be ascribed to the paucity of data on hair. Morphological characteristics of scalp hair have been exceptional in forensic sciences for identification purposes over a period of time (Jaydip, 2010). This is because scalp hairs have qualities that make them one of the most common pieces of proof to come upon when at crime scenes (Oien, 2009). "The forensic-friendly attributes of scalp hair include: it being readily available, persistent in fabric, ease of being shed, ease of transfer from one individual to another, good chemical stability and its resistance to decomposition" (Dachs *et al*.,2003; Bertrand *et al*., 2003).

Worldwide, albinism is a condition with a prevalence of 1 in 20, 000 (David, 2013; Lund, 2005). Although rare in the western world, it is quite common in Sub Saharan Africa likely because of consanguinity. The condition is highly prevalent in Sub Saharan Africa thus Ghana is no exception. In Sub Sharan Africa, studies from epidemiologists have shown that the prevalence of Albinism has been approximated to around 1 in 2000 to 5000 (Lund, 2005). With a population of around 50 million people, that makes albinism a major public health issue in Tanzania. In Europe and North America, by comparison, albinism is estimated to only affect between one in 17,000 and one in 20,000 of the population. With an estimated 30 million people, in Ghana, there are between 1, 500, and 5, 400 persons living with the condition based on the range above (Thompson-Hernandez, 2018).

In Ghana, there is an apparent paucity of information on hairs from people living with albinism. It is of interest to know how normal pigmented, and bleached and/or dyed hair colour compares with that of persons with Albinism. This will have forensic usefulness in cases of establishing identification in mass disasters or at crime scenes. For this reason, forensic scientists, criminologists, epidemiologists, ecologists, archaeologists, and anthropologists to facilitate the identification of individuals at crime scenes or in mass disasters must draw attention to research on hairs of persons with Albinism.

There are also many challenges ranging from the collection of hair evidence, examination of hair collected from a crime scene, and how to link the hair evidence to a person during forensic investigations in Ghana (Vaughn *et al*, 2009).

Further, there is a paucity of data on scalp hairs of Ghanaians; however, the literature on the morphological characteristics of hairs belonging to Ghanaian persons with Albinism is non-existent. From the scientific and forensic viewpoints, whether the lack of melanin in albino hairs affects hair features relevant for identification is researchable.

1.3 Aim

The aim of the study is to determine the morphological profile of hairs of Ghanaians with Albinism for anthropological and forensic use.

1.4 Specific Objectives

- To compare SEM morphological characteristics of hairs of Ghanaian Albinos and normally pigmented persons from the scalp
- To compare hairs from frontal, temporal and occipital regions of the scalp of Ghanaian persons with Albinism and normally pigmented persons.
- To compare the SEM-EDS of the hairs of Ghanaian Persons with Albinism and normally pigmented persons.

1.5 Hypothesis

H0: Albinism is not concurrent with altered morphological structure of hairs.

H1: Albinism is concurrent with altered morphological structure of hairs.

1.6 Justification

In Africa, the prevalence of Albinism is 1 out of 4000 people. The prevalence is even higher in Sub-Saharan Africa and it ranges from 1 out of 2000 to 1 out of 5000 people (Hong *et al*., 2006). According to Thompson-Hernandez (2018), there are more than 2000 persons with albinism condition in Ghana. The relatively high prevalence of in Africa and Ghana makes it important to study the morphological structure of the hair of persons with albinism to provide a database as well as compare the morphology of their hairs with normally pigmented hair. The optical light microscope even though used for the study of the hair structure, provides a poor topographical review of the features of the hair whereas the SEM will provide the surface structure and scale pattern of the cuticles of the hair strand thus giving more detail. The Scanning electron microscope will be used because of its ability to provide a better depth of field and resolution of the surface morphology of the hair. Also, the SEM will extend existing knowledge as well as providing potentially better distinguishing characteristics for studied hair. The SEM also has an Electron Dispersive X-Ray Spectroscopy (EDS) component that can help quantify the elemental components of the hairs.

Researches on hairs have not been ongoing until Aboagye *et al*. (2014) worked on the morphological features of androgenic hairs in Ghanaian males. Essel *et al*. (2019), whose study was on the the light microscopic of indigenous Ghanaian female scalp hair with styling procedures, followed this. Buame (September 2017, unpublished thesis) focused on the morphological analysis of human hair among Ashanti and Dagomba ethnic groups of Ghana and Kalmoni *et al*. (2019) studied the morphological features of hairs from the scalp, eyebrow, pubic regions and axilla of Ghanaian adolescents. These studies employed the use of the light microscope and results found were similar to existing proofs in literature. It is also of interest to find out whether the genetic mutations that result in albinism also affect the features of hairs apart from their pigmentation. This study will provide data on the morphology of the hairs of Persons with Albinism in Ghana.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Hair as an appendage of the skin

The skin serves as a residence for many mini-organs (referred to as appendages or adnexal structures) which includes hair, nails, mammary, sebaceous and sweat glands (Tiede *et al*., 2007). The hair shares a common ectodermal layer with the skin (Rossi *et al*., 2003) and it has two distinctive and recognisable parts strategically: the hair follicle, which is found in the skin and the hair fibre, is visible (Cruz *et al*., 2016). The skin is divided into the three layers which are the dermis, epidermis and subcutaneous layer as shown in Figure 1.

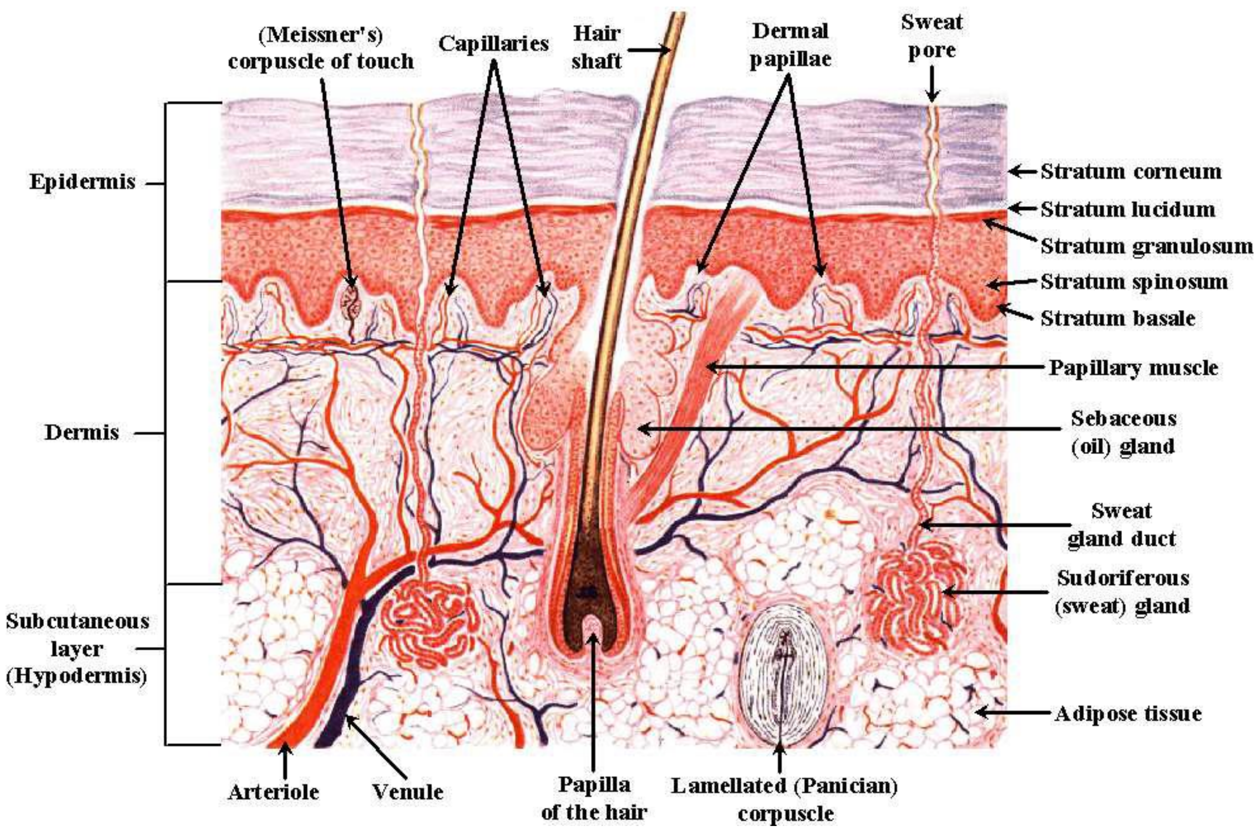


Figure 1: Composite diagram showing the Structure of the skin (Benner Jr and Levin, 2005)

The length of the hair extends from the root embedded in the follicle through the dermis, epidermis, stratum corneum and then the skin (Robbins, 2002). It then continues into a shaft and then terminates at the tip. The hair fibre creates a covering over the skin which serves as protection. During harsh conditions, the scalp hair serves as a physical barrier which protects the scalp (Nayak et al., 2017).

The dermis is a connective tissue layer made up of blood vessels that nourish the tactile corpuscles (sensory receptors), nerves and skin cells (Deedrick and Koch, 2004a). The dermis is a flexible and tough layer that keeps and protects underlying organs. The thickness of hairs varies depending on the region of the body it can be found. For example, the skin is thickest in the palms and soles but thinner in the eyelids. The dermis can also have varying thickness depending on the age and sex of an individual (Deedrick and Koch, 2004a).

Superior to the dermis is the epidermis. The epidermis like the dermis (Figure 2) differs in thickness at different areas of the body. The epidermis is a non-vascular layer comprised of living and dead skin cells. The dead cells are found in the two outer layers of the epidermis; the stratum lucidum and stratum corneum. The stratum lucidum consist of a clear layer of an indistinct cell with traces of nuclei. The stratum corneum is a layer of scale-like cells that are flattened. These cells do not have discernable nuclei and are made of soft keratin as compared to hard keratin which makes up the hair (Beary, 2014). The dead cells are continuously shed and substituted with the layers beneath so that the developing skin helps in protection. The living cells of the epidermis lie beneath the dead cells. They consist of a transitional layer of flattened polygonal cells with central nuclei. They are found in the layer of the epidermis called the stratum granulosum which produces the protein keratin. Underneath the stratum granulosum is the basal layer where cells split and sustain the epidermis. The cells in this layer form a nodule which grows and penetrate down into the dermis. These cells develop into the hair follicle (Paus and Cotsarelis, 1999).

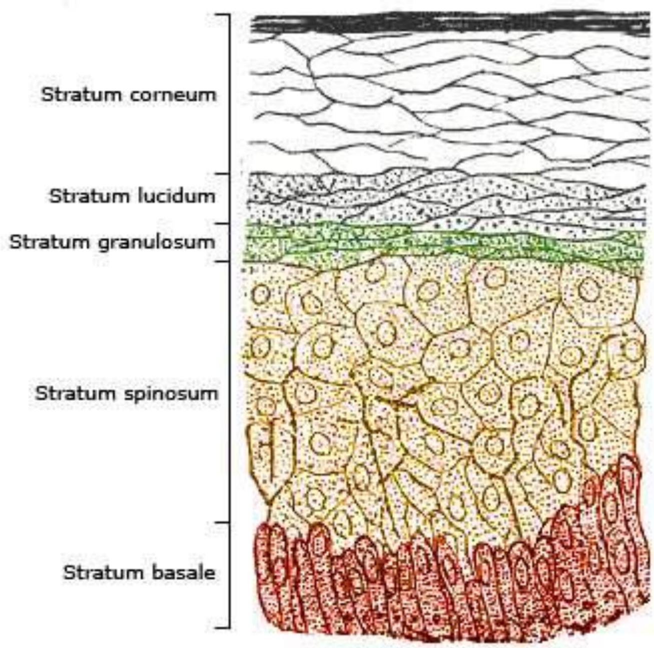


Figure 2: Structure of the epidermis (Benner Jr and Levin, 2005)

Dhugga *et al*. (2014) in their study showed a relationship between skin colour and melanin pigmentation as well as hair follicle density and hair size on the other hand. From the study, individuals with a greater concentration of melanin within the superficial layer of the skin had a lower follicle density and smaller sizes of hairs. On the other hand, persons who have lesser melanin concentration and light skin colour had more hair. Subsequently, it was proposed that hair growth may be linked to skin colour (Dhugga *et al*., 2014). These authors concluded that higher melanin levels in the basal layer of the epidermis might have constrained hairiness by affecting the capability of the skin to produce hair adversely.

2.1.1 Histogenesis of Hair Follicle and root

The hair follicle and its keratinized product are appendages of the skin which are present in almost every part of the body in mammals. Hair follicles are multifunctional and they generate hairs as well as provide epithelial stem cells used in wound repair. In the field of medicine, diseases of the hair follicle are of great concern (Brown and Krishnamurthy, 2018). The hair is considered as dead matter and is alive only when it is inserted in the scalp (pilose follicle). The hair fibre emerges and is considered as dead matter even though it appears to be growing (Longo *et al*., 2006; Dias, 2004). The hair follicle is a complex organ located in the skin and is responsible for the production of hair. It is an epidermal structure but develops mainly in the dermis of the skin (Efremenko *et al*., 2007). The hair follicle in humans is made due to epithelio-mesenchymal interactions commenced around the first trimester during foetal growth (Sen, 2010). Initially, hair follicles are formed in the skin of the embryo as an invagination of the epidermis into the dermis (McElwee and Sinclair, 2008).

A large number of hair follicles are contained in the dermis of the skin. The hair follicle is an epidermal structure but mainly develops in the dermis. It is associated with a cellular composition (Efremenko *et al*., 2007). The epidermis forms a bulge upon an initial signal from the dermis, around the bulge cells become concentrated and forms a dermal papilla with vascular features in reaction to an additional signal from the epidermis. The dermal papilla offers stimuli which help the new hair growth cycle (DiZinno *et al*., 1999). The dermis responds to the final message making the hair nodules grow continuously and the cells position themselves parallel to each other at a right angle to the longitudinal axis of the nodule (Robbins, 2012). The epidermal hair follicle is concave in nature and has a wide base (dermal papilla) and the two forms the hair bulb. At the lower region of the hair bulb, an outer connective tissue sheath form from the selfpropagating cells of the dermis, moving upward towards the skin's surface about mid-way up the follicle (Robbins, 2012).

The internal migrating cells are then separated from the external dermis by the external root sheath. The arrector pili often develop from this sheath. The sebaceous gland is an organ made up of a simple branched duct with acinar secretory units. There are a number of sacs in the duct which contain fatty oils and cells. A bundle of muscle smaller and inferior to the sebaceous gland is the arrector muscle. The pilosebaceous unit of the hair follicle includes the arrector pili muscle, the sebaceous gland and apocrine gland (Schneider *et al.*, 2009). Hair follicle formation occurs in the period of fetal and perinatal skin development primarily (Schneider *et al.*, 2009). According to Alonso and Fuchs (2006), no new follicles are formed postnatally. The apocrine and sebaceous glands lie on the side in the direction which the hair is inclined at an angle (Gillen *et al*, 1999).

During cold weathers, the arrector muscle contracts causing the hair to 'stand straight'. This results in goosebumps on the skin. Air is trapped by the hair which increases the amount of insulation for mammals. An inner root sheath develops from the lower part of the bulb at the matrix as nodules continue to develop and differentiate. The internal root sheath comprise of a weak cuticle layer with scales in a downward position, the Huxley layer which has nucleated cells, and the Henley layer which has rectangular cells with no distinct nucleus (Katz and Chatt, 1988).

The whole inner root sheath develops between the outer root sheath and the hair shaft cells which move distally by gliding against the outer root sheath. When the inner root sheath cells reach the opening of the sebaceous canal, proteolytic enzymes destroy them, thus releasing the hair shaft from the inner sheath (Deedrick *et al*, 2004a). Before getting to the sebaceous gland, however, the hair shaft, internal and external root sheaths are still linked. This part of the follicle is occasionally seen as the root of a pulled hair. The hair shaft is formed from the matrix cells at the lowest part of the hair follicle, almost 10% of the cells that leave the matrix form the mature hair and the rest (90%) builds up the root sheaths (Brown and Davenport, 2011).

Along the longitudinal axis, the whole hair filament can be divided into three regions (Figure. 3). The site for biological synthesis and organization is in the lower region located around the bulb of the hair. Differentiation of cells occurs in this region. The middle region is the site of keratinization. The hair shaft undergoes hardening or stability through cysteine cross-linking in this region. The long-lasting hair is that which appears from the surface of the skin and this part is seen in the uppermost region.

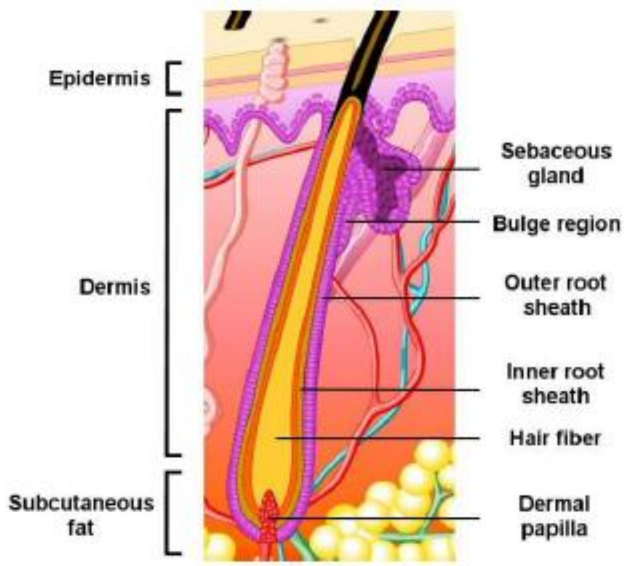


Figure 3: Diagram showing the Structure of the hair follicle (Taupin, 2004)

2.2 Morphogenesis of hair

Each mammal is believed to have a fixed number of hair follicles at birth and they do not increase in number. However, studies in mouse skin found hair follicles to increase during wound healing (Chuong *et al*., 2007). The contact between the epidermis and the underlying mesenchyme provides condition for the development of the hair follicle (Headon, 2009). The epidermis with the underlying mesenchyme remains in connection throughout the life of follicular units. Mutual connections take place between the epidermal keratinocytes and the mesenchymal cells. The former are responsible for the hair follicle and are involved in exact differentiation. The latter (mesenchymal cells) forms follicular papilla. Connections between these two cells are administered by a series of inductive events (Schneider *et al*., 2009, Botchkarev and Paus, 2003). Successive molecular events in the follicle development decide the future physical appearance of a hair strand once the distribution of follicles has been established (Paus and Cotsarelis, 1999).

During the process of embryogenesis, the hair follicle undergoes development and differentiation which are grouped are grouped mainly into induction, organogenesis or progression and cytodifferentiation or maturation which is defined as a germ, peg and bulbous follicles morphologically as seen in figure 4 (Schmidt-Ulrich and Paus, 2005; Paus and Cotsarelis, 1999). During the induction stage of the hair follicle, Wnt-mediated signals transduction starts in mesenchymal cells guiding the thickening of the overlying epithelium to form a placode. The progression and maturation stages follow the induction stage respectively. The progression and maturation stages are described by precise molecular interactions. The progression stage consists of signal interactions which are complex. Epithelial cells direct the underlying dermal cells to multiply and form a dermal condensate which give signs to the epithelial cells to multiply and grow downwards into the dermis (Schneider *et al*., 2009). Dermal condensate is enclosed with follicular epithelial cells during cytodifferentiation. It forms a separate dermal papilla which directs the ectoderm to shape the whole hair follicle through the action of growth factors (Rishikaysh *et al*., 2014; Nissimov and Das Chaudhuri, 2014). During the development of the follicle, the hair is produced from the constant splitting up of the proliferative (matrix) cells following terminal differentiation of the offspring to be produced (Alonso and Fuchs, 2006).

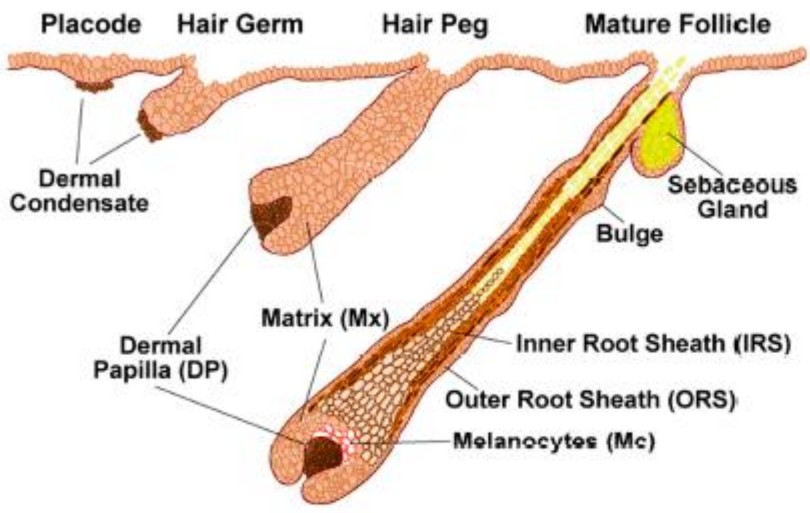


Figure 4: Embryonic stages of human hair follicle morphogenesis (Fuchs, 2008).

2.3 Hair shaft Structure

The hair shaft consists primarily of keratin which makes up between 65-95% of the hair shaft, lipids (structural or free), water, trace elements and pigments (Velasco *et al*., 2009). It is resolvable into three main layers, namely; the cuticle, the cortex, and the medulla as diagramatized in Figure 5 (Harrison and Sinclair, 2003).

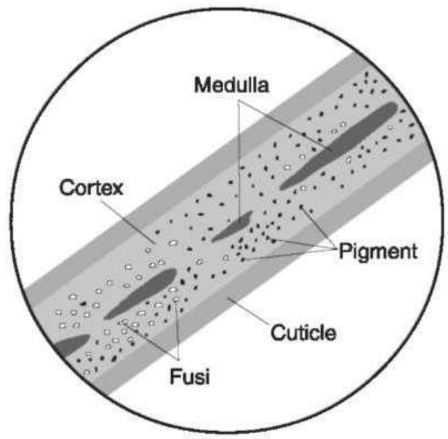


Figure 5: Structure of the hair shaft (Tridico *et al*., 2014)

2.3.1 The cuticle

The outmost layer of the hair shaft is the cuticle (Figure. 6). The cuticle results from the matrix cells at the top of the dermal papilla. The number of cuticles varies between different species. In a single row, the cuticle cells move distally and as hairs grow, the cells form five circumferential layers approximately above the human scalp (Bhushan, 2010; Kemporton *et al*., 2010). The hair when it develops first from the follicle has about six to ten overlying scales (Bhushan, 2010). The scales have a proximal end which attaches to the cortex and a free edge directed outward (Draelos, 2000).

Four lamellar components make up the cuticle and they differ in chemical composition significantly (Figure. 7). The epicuticle (12% cysteine content) is the most outer layer of the hair shaft. According to Robbins (2012a), the thickness of the epicuticle is 25 Angstrom. Due to the high degree of crosslinking, this layer is very hard and thus acts as a diffusion barrier. Below the epicuticle is the A- layer which contains resilient cysteine greater than 30%. The resistant cysteine is existent in other regions but in reduced quantities. The A-layer has a majority of its cysteine residues engaged in intermolecular crosslinking which renders it tough for its protective role of the hair from mechanical injury (Swift, 1999). Beneath the A-layer is the exocuticle (15% cysteine content). The exocuticle is also recognized as the B-layer. The endocuticle is low in cysteine (about 3%) and the weakest among the layers. It consists of cell organelles and remnants of cytoplasm. Enzymatically, it has degradable proteins with amino acids which predominantly have anionic side chains (Chattha *et al*., 2011).

The scale surrounds and gives protection to the internal part of the hair as well as helps to hold the hair to the skin. Like the fish scales, the cells are flat and overlapping. The size of cells can have a thickness between 0.5 µm and 1 µm and a length of 45 µm (Kolowski *et al*., 2012). The scales are generally pigmented and appear translucent (Robertson, 2017). Scales have varied shapes and patterns. These patterns are very important since they are a diagnostic feature of hair, important in the investigations which help in identification of hairs of species of mammals (Robbins, 2012b). Studies have shown that the hair makes physical contact with the environment through the surface of the cuticle (Stamm *et al*., 1977b; Stamm *et al*., 1977). These studies have showed the structure and the preservative state of the cuticle and how they incident light which is either reflected, refracted or transmitted. The cuticle serves as a medium through which the hair interacts with light. The smooth nature of the cuticle enables it to reflect light and also prevents friction among the shafts. The cuticle structure can change due factors such as washing, brushing, and environmental factors as well as time (Harrison and Sinclair, 2003).

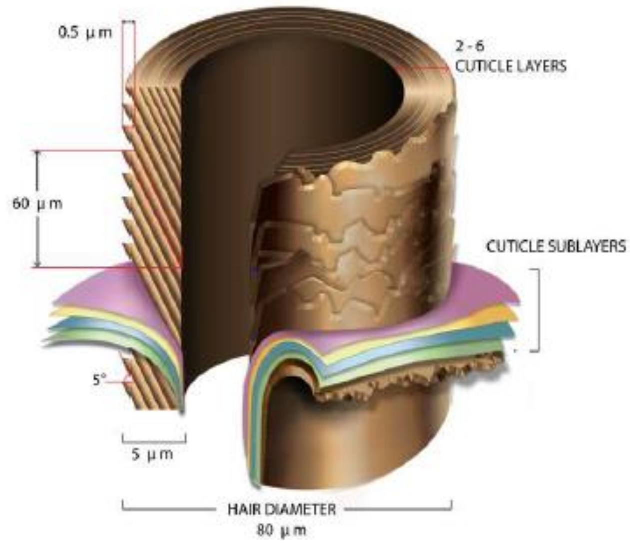


Figure 6: Geometric arrangement of the cuticle of hair (Robbins, 2012b)

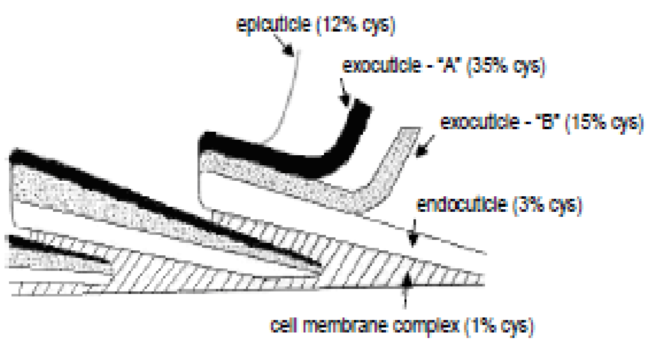


Figure 7: Diagram showing lamellar arrangement of cuticle cells (Swift, 1999)

The cuticle is made up of three elementary shapes (Figure 8): coronal, spinous and imbricate (Deedrick and Koch, 2004b; 2004a). The coronal known also as the crown-like scale pattern is found in hairs which have very fine diameter. They look like paper cups stuck on each other. Coronal scales are not normally found in the hairs humans but rather in small rodents and bats. Spinous or petal-like scales are triangular in shape and project from the hair shaft. They are found at the proximal region of mink hairs and on the fur hairs of seals, cats, and some other animals. Spinous scales are never found in human hairs. The imbricate or flattened scales type contains overlapping scales with slim margins and is commonly found in human hairs as well as many animal hairs. There is a possibility of some hairs having combined scale types as well as various scale types. Human hair can therefore be differentiated from non-human hair based on their scale pattern. The scales on animal hairs display many differences like coronal and spinous patterns, while in humans, the scale patterns are imbricate.

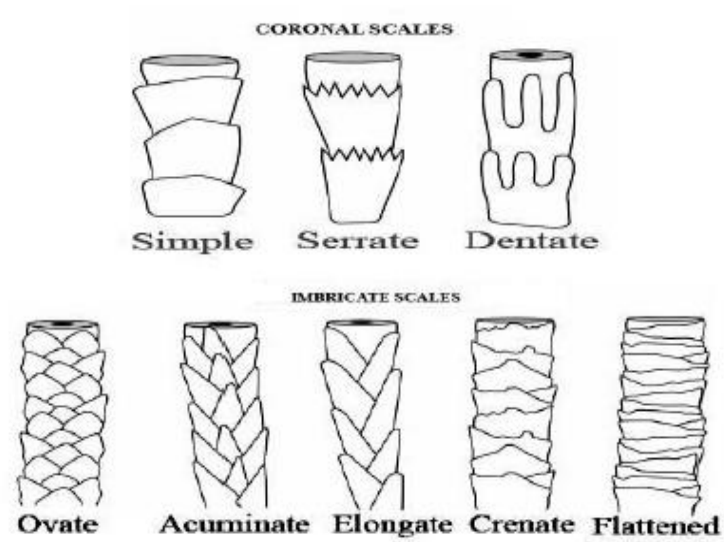


Figure 8: Types of cuticular scales based on scale margins

(Source: http://www.microgallery.com/hair.asp%; Date accessed 3rd January 2020)

The cuticular features of hairs of mammals have been widely studied. The scales of the cuticle can vary between taxa and can be of importance by helping in identification (Backwell *et al.*, 2009). Teerink (2003) in his study recognized that the position of scale with the longitudinal direction of hair may be transverse, intermediate or longitudinal while scale patterns can be petal-shaped, waved, transitional or mosaic (Figure. 9). The scale margins can be described as smooth, rippled or frilled. Using the width of the hair, scales could be big and few or numerous and packed closely. The textures of scale patterns vary largely from specie to specie and may even differ along with a particular hair (Perrin and Campbell, 1980).

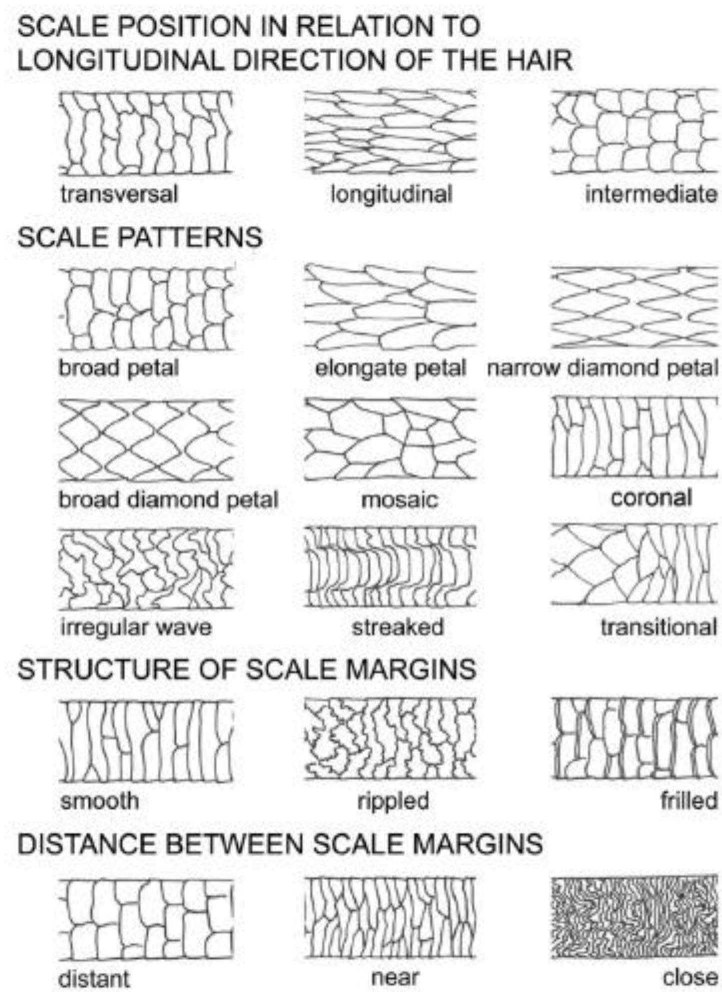


Figure 9: Diagrams showing Scale features used in the identification of hair (Source: Backwell *et al*., 2009)

2.3.2 The cortex

The cortex makes up the bulk of the hair shaft and it is located between the cuticle and the medulla. It is made of crystallized α-keratin fibrils. Under the light microscope, it appears homogenous but there may be variation in their shape and size. Depending on the keratinization process, cells of the cortex may appear spherical at the proximal end and may become spindle-shaped at the distal end (Taupin, 2004). Hair cortex is filled by cross-links of cysteine and hard cells separated by cell membrane complexes (CMC) (Schlake, 2007). The thickness ranges from 1.0 µm to 6.0 µm and approximately 100 µm in length. Amongst the cells are small air spaces called the fusi (Lavker *et al*., 2003). The colour of hair is recognized by the type, size and number of melanin granules found in the cortex (van der Mei, 2002).

2.3.3 The medulla

The medulla can be continuous, discontinuous or absent and is made up of a small amount of fibre mass (Figure 10). Human hair can be differentiated from non-human hair using the medullary index. The index is dividing the medulla width by the width of the hair (Deedrick and Koch, 2004b; Deedrick and Koch, 2004a). The medulla has a mixture of variable and loosely shaped cells linked by a filamentous network and pockets of air. It is responsible for maintaining the diameter of the hair without increasing its weight. It has been proven that the medulla plays a role in the coarse re-growth of hair after trimming. It is believed that this region of the hair is activated to increase in size (Jackson and Jackson, 2004) after shaving. It also plays a vital role in providing thermal insulation (Beary, 2014). Little chemical and mechanical properties of the hair are provided by the medulla (Robbins, 2012b). In most mammals, the medulla occurs but it is absent in some types of hair like the vellus hairs from humans (Bisbing, 2002). Studies using electron microscope has shown that the medulla presents three distinct sub-units; globular structures, unorganized cortical cells and smooth covering cells and also two kinds of medulla which were identified as thin and thick (Wagner *et al*., 2007).

The medullary index is used to distinguish different types of hair be it human or animal hair. (Deedrick and Koch, 2004b; Deedrick and Koch, 2004a). The index is one third and lower in human hair and more than one third in non-human hair. The bigger medullary index in animals is as a result of the thickness of the medulla in their hair (Deedrick and Koch, 2004b; Deedrick and Koch, 2004a). According to Essel *et al*. (2019), three different hairstyle groups (natural unstyled, natural styled and relaxed styled) used in their study showed a significantly high proportion of medulla and some absent medulla. From their study on scalp hairs, the natural unstyled groups showed a great proportion of hairs with medulla absent followed by the natural styled group and the relaxed hairstyle group. According to Kalmoni *et al*. (2019), the presence of the medulla conformed to the hair shaft diameter.

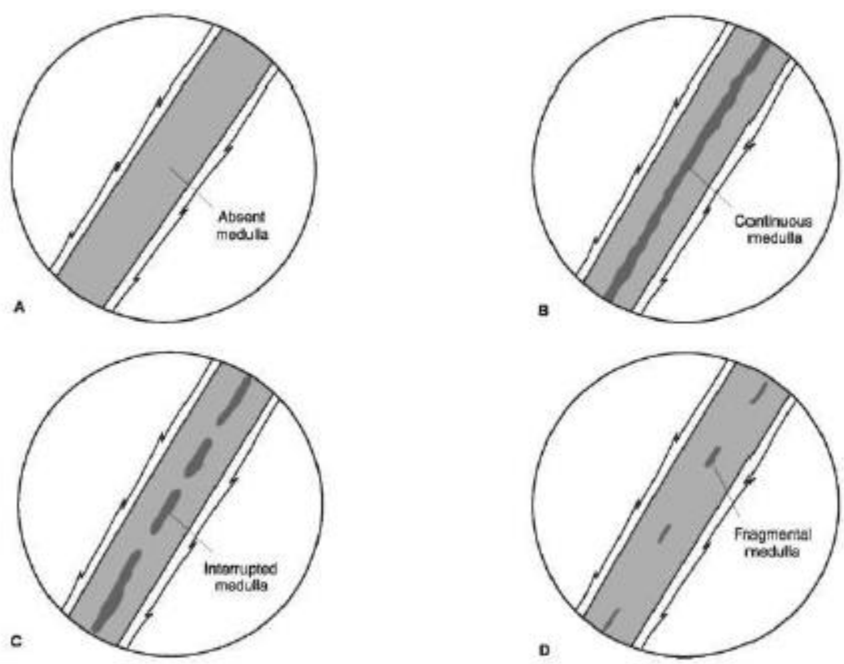


Figure 10: Medulla types in human hairs (Robbins, 2012b)

2.4 Classification of human hair

Depending on the length and thickness of hair follicles, Sen (2010), identified three hair types in humans. These are lanugo, vellus and terminal hairs. Lanugo hairs are soft and fine and can be formed in the first cycle of hair growth. Lanugo hairs grow all over the body and their functions is to maintain body heat and are shed about the eighth month of development (Sen, 2010). Some of these hairs grows and lasts until the first three months of after uterine life. Vellus hairs replace Lanugo hairs. They are short, fine and unpigmented and grow in most places of the human body in both males and females. The hair follicles of vellus hairs are usually not connected to the sebaceous gland and are less than 2 cm in length. Terminal hairs, on the other hand, are developed hairs which are lengthier, coarser, darker, and thicker compared to vellus hairs. The growth of terminal hair is more obvious than in vellus hairs with the terminal hairs having an extended anagen phase (Sen, 2010). The terminal hairs have a big hair follicle and a medulla ocassionally. According to Randall (2007), at puberty vellus hairs located in the axilaary and pubic regions including those on the chest, legs and face (in the case of males) are transformed to terminal hairs. Scalp, eyebrows, eyelashes, beard, pubic and peri-anal hairs are all terminal hairs.

Human hair has been classically categorized according to the racial origin. These are Mongoloid (Asian origin), Caucasoid (European origin) and Negroid (African origin) hairs. Mongoloid hair has a larger diameter and is spherical. A section cut through an African hair shows an ellipsoid shape since highly irregular in its diameter. The Caucasian hairs have an intermediate shape and diameter and show an oval shape when a section is cut through it (Menkart *et al*., 1996; Syed *et al*., 1995; Kamath *et al*., 1984). The Negroid hair is characterized by tightly spring-like coils and interwoven hair shafts therefore combing may result in daily breakage (Khumalo *et al*., 2000). According to Khumalo *et al*. (2000), it was proposed that grooming procedures such as dreadlocks (twisted into locks) could increase hair length as well as reduce knotting. According to Syed *et al*. (1995), Negroid hairs have low tensile strength and break easily as compared to Caucasian hairs. And also they stated that because of the curly configuration of Negroid hairs, it is quite difficult to comb than Caucasian hairs. Studies by Menkart *et al*. (1996) have also shown that all three racial hair types have similar amounts of proteins and amino acids constituting keratin. Even though the hair has been classified into three main categories which are Mongoloid, Caucasian and Negroid, it has been studied that this broad classification can hardly account for the human biodiversity resulting from both multiple and recent or past mixed origin. Also, the racial classification was considered as broad since same hair properties could be seen in people with different ancestry whiles others of the same origin may have different hairs depending on genetic recombination or local polymorphism. In a recent study by De La Mettrie *et al*. (2007), the hair classification was expanded into eight main subgroups by considering three readily accessible parameters: number of waves, curl diameter and curl index (De La Mettrie *et al*., 2007). In the process of classifying hair, structural features of the hair follicle have been taken into consideration; these include the follicular infundibulum volume, hair follicle density and hair shaft diameters (Erdogan, 2017).

2.5 Chemical components of the hair

Human hair contains about 65-95% keratin proteins depending on the amount of moisture content, water, lipids, pigments and trace elements. The human hair is a combined system with chemical components acting together (Velasco *et al*., 2009).

2.5.1 Proteins

The proteins found in human hairs are both positively and negatively charged. They are amphoteric. The cationic character is due to the protonated side chains of histidine, arginine, lysine and the small portion of free amino groups at the ends of the peptide chains. The characteristic of anionic groups owes to the side chains of glutamic acid, aspartic and carboxyl end groups.

The protein structure and composition in all ethnic hairs are similar though the quantities and amino acid types differ from person to person (Menkart, 1984). Amino acids composition of hair and their relative quantities are shown in table 1.

Table 1: Amino acid composition of a human hair (Nishikawa, 1998)

Amino Acid	% of Total Residues	Amino Acid	% of Total Residues
Lysine	2.7	Proline	8.4
Histidine	0.9	Glycine	6.4
Arginine	5.8	Alanine	4.6
Aspartate + Asparagine	4.9	Half cysteine	17.8
Threonine	6.8	Valine	5.8
Serine	11.7	Methionine	0.6
Glutamate + Glutamine	11.4	Isoleucine	2.6
Leucine	5.8	Tyrosine	2.0
Phenylalanine	1.6		
Total	99.8		

The major amino acids found in the hair from table one are glutamic acid, cysteine and serine which make up 11.4%, 17.8% and 11.7% of hair protein respectively. Cystine residues give stability to the hair because of its strong disulphide linkage except for chemical processes like weathering and reduction. The different physical properties of human hairs are as a result of the different cysteine contents between various structures. Higher cysteic acid, Lower cysteine, lower tyrosine and lower methionine content in bleached hairs differentiate them from virgin hair

(Robbins, 2002). This agrees with Zahn's study which showed that at the disulphide bond of proteins, bleaching agents react with human hair protein in 1966.

Keratin proteins are the main components of human hair. They form the building blocks of hair and part of the human skin and nail (Plowman, 2007). In the process of hair formation, keratin found in the cells becomes crystalline as the cells differentiate to produce the hair fibre. The keratinized cells contain materials that prevent various environmental constraints such as flexion, tension, friction, UV radiation, and chemical assault (Bouillon and Wilkinson, 2005). The molecular weight of keratin ranges from 40 to 70 kDa. The hair, nails, claws of mammals, including humans are made up of Alpha-keratins mainly in α-helix conformation. In birds and reptiles, the beaks, claws, shells and feathers are made up of Beta-Keratins with β-sheets conformation. Both Alpha-keratins and Beta-Keratins can have both conformations. There are two types of Alpha-keratins; type I and type II. Type I are smaller in size as compared to type II which are larger (Robbins, 2012). According to Conway and Parry (1988) keratins can be divided into 'a' and 'b'. The 'a' (type Ia and IIa) keratins are hard keratins and are found in hairs and nails. The 'b' (type Ib and IIb) keratins are soft keratins and can be found in the epidermis.

The amino acid structure of human hair keratin is unlike other keratins. There are major difference which relates to the cysteine residue content and the glycine content. The amount of cystine (high amount of disulfide bonds) in human hair keratin gives it a durable and tougher structure with good thermal, mechanical and chemical properties. All keratin types contain high aspartic and glutamic content residues (Yu *et al*., 1993). The amino acid content of hair can be changed by several factors which include genetic variation, age, diet, hair treatment, analytic and extraction methods employed. For example, masculine hair has more cystine residues than feminine hair. Also, the tip of the hair of the scalp has a reduced amount of cystine and cysteine residues significantly than the root end due to weathering (Cruz *et al*., 2016).

2.5.2 Water component in hair

Water is an essential component of keratin fibres and an important factor in the stabilization of the protein structure (Bouillon and Wilkinson, 2005). Water content, therefore, is a key parameter relating to its cosmetic and physical parameters. The water content of keratin fibres is dependent on the dryness of the fibre and the air relative humidity (Robbins, 2012). The hair is hygroscopic and can absorb a lot of water. The hair readily absorbs water as high as 75% within four minutes (Bouillon and Wilkinson, 2005). The weight of hair impregnated with water increases in weight by about 12%-18% (Cruz *et al*., 2016). The swelling of hair is anisotropic and at relative humidity from 0% to 100%, the length and diameter of hair increases by 2% and more than 15% respectively. Damaged hair can take up more than 45% of its weight of water as compared to virgin hair which can absorb 30% (Bouillon and Wilkinson, 2005). This happens usually since water is expected to be absorbed to the hydrophilic matrix of the cortical cells within the boundary with the myofibrils. The hair size is increased by diametric swelling since water can distort slightly the structure of the myofibrils and oppose the longitudinal enlargement of the matrix. Even though water is absorbed readily by the hair, it has some binding selectivity in the molecular structure of the cortex (Bouillon and Wilkinson, 2005). The absorption of water by the hair is linked to the number of lipids in the hair and pH level. In the chemical relaxation of hair, one of the damages that occur is a monomolecular layer of fatty acid bound covalently to the cuticle. The hydrophobic layer impedes water from entering the hair shaft and altering its physical properties (Miranda-Vilela *et al*., 2013). Treating the scalp hair with chemicals therefore makes it penetrable to water which causes the shaft. Essel *et al*. (2019) posited that the shaft diameter of chemically styled hair is greater because it becomes more penetrable to water due to the removal of the waterproofing component of the hair. To preserve the natural structure of the hair, reduce the structural damage as well as reduce the water penetration capacity, Essel *et al*. (2019) suggested that Afro hair should barely be treated with chemicals.

2.5.3 Lipids

Lipids make up about 4% of the weight of hair fibre. They can be internal or external. The internal lipids can be free or part of the Cell Membrane Complex (CMC) and are believed to be situated in the intercellular spaces, as part of the β-layers (Robbins, 2012; Bouillon and Wilkinson, 2005). Lipids of human hair include triglycerides, cholesterol, cholesterol sulfate, cholesterol esters, free fatty acids, squalene, paraffin, and ceramides (Bouillon and Wilkinson, 2005). A main constituent of exogenous lipids is 18-methyleicosanoic acid (18-MEA), attached covalently to the cuticle surface. 18-MEA serves as a lubricant to decrease resistance between hair fibres. The lack of 18-MEA influences the sensory perception of hair especially with when dry (Tanamachi *et al*., 2010). The content of lipid in hairs is based on various factors like age, gender and ethnicity (Cruz *et al*., 2013).

2.5.4 Pigments

The pigmentation of hair in mammals is imparted by the pigment melanin. Melanin is produced by specialized dendritic cells called melanocytes which are derived from neural crest cells. Melanocytes are present in the form of discrete granules known as pigment granules and located near the hair bulb. Melanin synthesis occurs in melanosomes which vary in shapes and sizes. The colour of the hairs is dependent on the pigment content of the shaft. Differentiated melanocytes secrete melanosomes into keratinocytes in their surroundings giving rise to melanised hair (Ohyama, 2007; Morris *et al*., 2004). The hair pigmentation is controlled by follicular melanin units. The melanocyte population of the human skin comprises of epidermal and follicular compartments. Melanocytes have a multifunctional enzyme, which catalyses the preliminary events of melanogenesis. Other proteins that catalyse melanogenesis are tyrosinase-related protein (T-RP) I and II. There are two types of pigments produced by the mammalian follicular melanocytes; pheomelanin and eumelanin (Figure. 11).

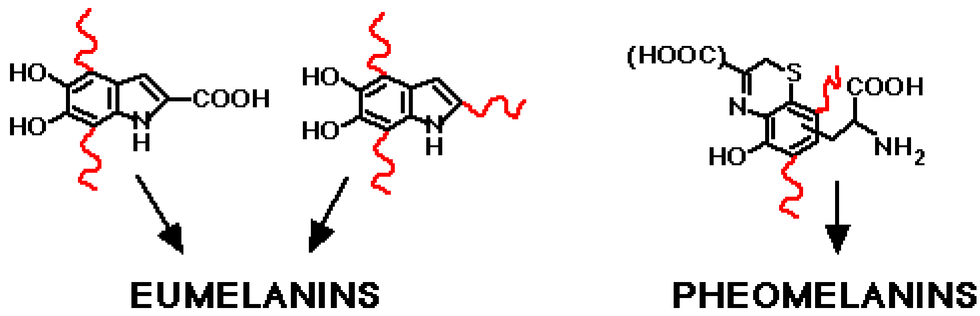


Figure 11: Chemical structure of Eumelanins and Pheomelanins (Colbert, 2004)

Pheomelanin is the type of melanin found in Caucasian hairs. It is responsible for light colours: fair and red. Eumelanin produces dark colours such as brown and black (Rees, 2003). The classification of melanin is based on the amount of melanin produced and the relative amount of either pheomelanin or eumelanin. The ratio between pheomelanin and eumelanin determines one's hair colour (Robbins, 2002). The absence or relative absence of these pheomelanin or eumelanin gives rise to white hair. Vincensi *et al*. (1998) observed that amount of pheomelanin and eumelanin in red hair varies with age, sex and colour. The melanocytes found in the hair follicle stop working efficiently as individual ages and the levels of melanin decrease resulting in grey (paler) hairs. Eumelanin in small amounts gives place to grey hairs (Robbins, 2012). According to Trueb (2009), the grey and white colour of hair is due to reduced melanin content of the hair follicles.

In the biosynthesis of eumelanin and pheomelanin, the tyrosinase enzyme plays a vital role. In persons with albinism, there is reduction photoprotection owing to small amount of eumelanin. Eumelanin plays a vital role in photoprotection. On the other hand, pheomelanin provides some amount of photoprotection against solar radiation but there reactive oxygen species generated during biosynthesis (de Vijlder *et al*., 2013). In Africa, OCA2 is the commonest form of Albinism (Manga *et al*., 2013). Persons with OCA2 phenotype do not have eumelanin but some amount of pheomelanin which can increase gradually with time (de Vijlder *et al*., 2013).

2.5.5 Trace Elements

Hair contains variable amounts of inorganic elements lower than 1% (Bouillon and Wilkinson, 2005). These are alkaline elements (Potassium and Sodium), alkaline earth metals (Magnesium, Calcium and Strontium, metalloids (Silicon and Phosphorus) and other metals (Zinc, Iron, Manganese, Cadmium, Lead, Mercury, Arsenic, Selenium and Calcium) (Bouillon and Wilkinson, 2005). In the field of diagnostic medicine, trace elements can be used in the detection of accumulation of several elements associated with systemic disease and compare to the number of trace elements in internal organs (Robbins, 2012). The use of hair cosmetics may also add up to the trace elements found in the hair fibre (Cruz *et al*., 2013).

2.6 Hair Growth

There are three different stages in which hair growth occurs. These are anagen, catagen and telogen stages. For each of these stages, androgens or hormones control and stimulate the activity of male sex gland (Robbin, 2012a). The changes in the growth of hair are affected by differences in the follicle types in the same body region, different body regions and species (Wilson *et al*., 2010).

2.6.1 Anagen

This stage of hair growth is characterized by increased growth whereby there is an increment in the metabolic activity of the hair bulb. In this phase, there is active growth where the follicle enlarges and takes shape and produces the hair fibre. According to Macko *et al*. (1999), the anagen phase can be divided into six sub-phases: the proanagen (first four sub-phases) and mutagen (a fifth sub-phase). Through the first five stages, the stem cells of the hair proliferate and enclose the dermal papilla then grow downward to the skin and begin to multiply hair shaft and internal root sheath respectively. Afterwards, the melanocytes of the hair matrix start to develop pigment and the hair shaft begins to ascend. In the last stage of anagen, the hair bulb and dermal papilla are seen. Finally, a new hair shaft appears from the skin (Buffoli *et al*., 2014; Krause and Foitzik, 2006).

Cells in the anagen phase undergo restoration and the hair bulb starts to develop into the dermis around the dermal papilla. The hair starts to form as the follicle, gets to the sebaceous gland and then with the matrix, it begins to encounter an increased rate of growth. The anagen phase can last between two and six years approximately in the scalp hair of humans (Robbins, 2012a).

Synthesis and pigmentation of hair shaft take place only in the anagen (Krause and Foitzik, 2006). The length of the fibre is usually reliant on the time of the anagen or actively growing phase of the follicle (Jones, 2001). The anagen phase is featured by regulatory proteins such as several WNT proteins, sonic hedgehog, Bone Morphogenic proteins (BMPs) and receptors. Insulin-like growth factor-1 (IGF-1) , hepatic growth factor (HGF), vascular endothelial growth factor (VEGF), fibroblast growth factor-7 are believed to be essential in the maintaining the anagen phase (Schneider *et al*., 2009).

2.6.2 Catagen

The transitional stage between the anagen and the telogen phases is the catagen phase. The mitotic division that takes place in the matrix of the hair bulb is reduced and eventually stopped. Even though new cells are not produced any more, cells that already exist migrate distally to keratinization regions. The cells contract to form a bulge. It is argued by researchers that the bulge is the definite site of the source for stem cells of the hair follicle (de Viragh and Meuli, 1995).

Catagen phase lasts for approximately two weeks (Wilson *et al,* 2007) and after the phase is completed, the telogen phase commences.The catagen stage undergoes eight different sub-stages. In the commencement of catagen, melanogenesis is terminated in the hair bulb. Follicular epithelium and mesenchyme show cyclic changes in apoptosis and differentiation. Apoptosis that occurs in the papilla is due to expression of bcl-2, although FGF5 is an important inducer of catagen. Studies have shown that FGF deficient mice have prolonged anagen phase. Several inducers of catagen include IL-1b, TGF-β1, FGF5, neurotrophins such as NT-3, BMP2, NT-4, BMP4 and TNFα (Schneider *et al*., 2009).

2.6.3 Telogen

Complete hair growth ends in the telogen phase. In this phase, cell differentiation and cell division have ceased. The hair bulb below sebaceous gland has significantly undergone atrophy as well as a decrease in size. Telogen lasts for just some few weeks according to Robbins (2012a). When hairs are plucked in the telogen phase, the anagen phase resumes immediately but in this case, a longer time might be taken for the regeneration of the hair follicle before hair growth commences (Velasco *et al*., 2009). Depending on the region of the body a human hair is taken from, it takes 61 to 147 days before the hair regenerates (Walter, 2001).

Several modulatory agents like thyroid hormones, retinol, ACTH, androgens, and prolactin influence the telogen phase. This phase is the hair cycle target site. The oestrogen receptor expression is thought to limit the telogen papilla fibroblast even though no specific molecular markers associated with the telogen follicles have been determined. Basonuclin and FGF-5 are also expressed from the telogen follicles of germ cells (Stenn and Paus, 2001).

2.7 Hair cycle

Periodic changes occur in the hair follicles during postnatal life. There is a period of consistent growth which is approximately 1.0 cm per month. Continuous growth occurs for three to five years during the anagen phase (Figure 12). Hair growth stops and is followed by the catagen phase which is a brief stage and then a two to four-month resting stage which is the telogen phase. During this stage old hair comes off. Some studies have shown that there is an additional phase, the exogen phase, during which hair fibres are actively shed. In the hair cycle process, the hair follicle becomes empty after telogen hair has been removed and before a new anagen phase occurs. This stage is named the kenogen phase (Bernard, 2012; Guarrera and Rebora, 2005).

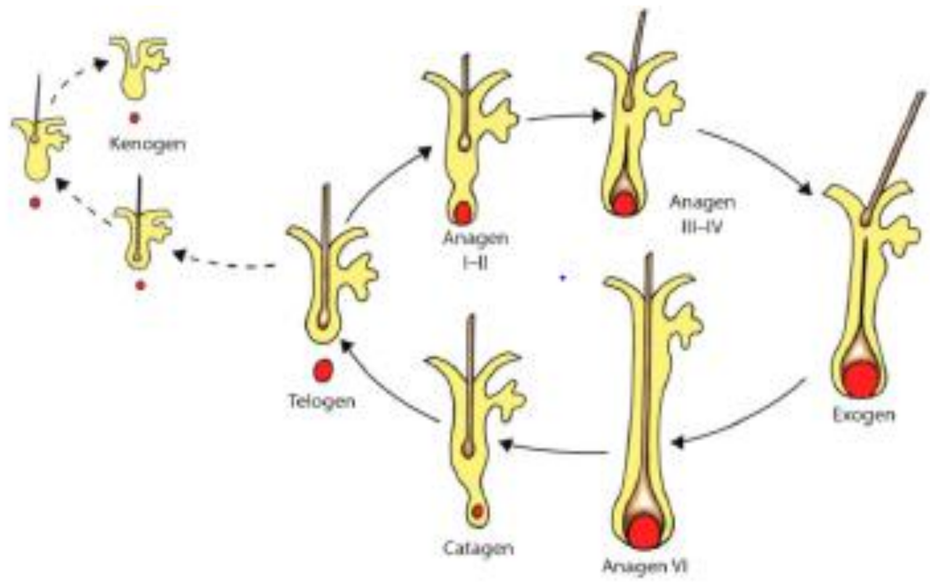


Figure 12: Diagrammatized Hair life cycle (Vogt *et al*., 2008)

Although hairs in all body regions undergo this cycle, the extent, duration of the phase and the length of the fibres differ between areas of the body and persons. These variations are dependent on genetics, age, gender and health status (Araújo *et al*., 2010). Further, the extent of cycle phases will determine hair length and replacement (Westgate *et al*., 2013). The length of hair is defined by the duration of the anagen stage. About 85% to 90% of all scalp hair at any given point is in the anagen phase (Bernard, 2003). The characteristics of hair in other body regions are regulated during the cycle and this helps in giving further insight on how hair loss and hirsutism occurs (Randall, 2008). The changes in the cyclic transformation of hair are controlled by local signalling milieu. Through autocrine, paracrine and endocrine paths, signalling is dependent on several growth factors which include cytokines, hormones, neurotransmitters and their receptors, transcription factors and their enzymes. Studies have shown that even when the hair follicle is isolated in organ culture, hair follicle cycling is capable of continuing. The hair cycle is therefore considered to be an autonomous phenomenon (Schneider *et al*., 2009; Paus and Foitzik, 2004).

The hair cycle of mammals is a regulated system during development and morphogenesis which comprises many factors such as BMPs, Sonic hedgehog (Shh), FGF7, HGF, SGK3, and Msx2. BMPs have been involved in the hair follicle (Porter, 2003; Kulessa *et al.*, 2000). Sonic hedgehog (Shh) and FGF7 are help in the commencement of anagen phase. HGF, SGK3 and Msx2 preserve the growing hair follicles by protection against programmed cell death and efficiently preventing the change of follicles from anagen to catagen (Alonso *et al.*, 2005; Porter, 2003). Signalling by WNT proteins has shown to keep follicles in anagen (Lowry *et al.,* 2005; Lo Celso *et al.,* 2004). Stenn and Paus (2001) have shown that trauma or wounding, initiates hair growth.

On the other hand, TGFα, TGFβ and TGF5 help in the initiation of catagen (Porter, 2003). FGF5, EGF and neurotrophins such as BDNF and the p75-neurotrophin receptor are also known to promote the transition to catagen (Schmidt-Ullrich and Paus, 2005; Foitzik *et al.,* 2000). Parathyroid hormone-related protein (PTHrP) plays a role as a negative regulator of the hair cycle by stimulating entry into catagen (Gonterman, 2008). It has been suggested by Diamond *et al.* (2006) that PTHrP might play a role as an anti-angiogenic factor during late anagen. The hair cycle parallels morphogenesis even in the process of multiple signalling events and incorporates developmental pathways during different stages of the hair cycle (Blume-Peytavi *et al*., 2008)

2.8 Functions of the hair

In the survival of mammals, hairs play a very significant role (Randall, 2007). Hair plays a role in thermoregulation and prevents heat loss. The hair traps a layer of air on the skin surface which prevents heat loss (Randall, 2007; Popescu and Hocker, 2007). In ecology, survival is very important, in the arctic fox, for example, its hair colours provide camouflage which helps contribute to survival (Stenn and Paus, 2001; Tobin and Paus, 2001). In medicine, there is little or no importance associated with hair loss since it is not life-threatening (Randall, 2007). In humans, the most important role of hairs is communication and protection (Randall, 2007).

Human hair is used for recognition and also determines the physical attractiveness of an individual (Rossi *et al*., 2003). Over the centuries, scalp hair has been used as a medium to communicate social status or identity. It has been shown in several studies that conditions associated with loss of hair have negative psychological effects (Cash, 1992). For years hair was seen to be of aesthetic importance until recently when hair follicle epithelial cells and their contribution to skin healing attracted particular interest. It is believed that the outer root sheath of the epithelial cells provides cell replacement in response to wounding. In wound healing, there are probably progenitor cells in the dermal sheath which are of importance (Jahoda *et al*., 2001). The hair also plays a necessary role in skin re-pigmentation. Melanocytes are located in the bulb epithelium of adult follicles and also the epithelial outer root sheath cells at the infundibulum and lower part of the follicle.

Active (DOPA-positive) melanocytes exist in the epidermis of normal skin and some inactive (DOPA-negative) melanocytes in the outer root sheath of the lower part of a normal hair follicle. The inactive melanocytes are believed to form a melanocyte reservoir in the skin. For instance, during re-pigmentation of vitiligo, outer root melanocytes multiply and migrate to the epidermis. The human hair also provides Ultra Violet (UV) protection for the scalp (Rossi *et al*., 2003).

2.9 Significance of human hair

Principally, the microscopic description and comparison of the hairs of humans are useful in the field of forensics to relate crime with perpetrators and victims. In archaeology, forensics and health the human hair has been seen to be useful (Thompson *et al.*, 2014). Thompson *et al.* (2014) opined that the hairs found from archaeological sites and forensic investigations are able to give records on the geochemical environment of individuals. Hairs obtained provide extraordinary opportunity to restore the environment, residential location and diet of persons. For instance, hair obtained can be used to determine the number of weeks or months an individual has lived before death and this is reliant on the growth rate as well as the length of the strand available for isotope analysis (Thompson *et al*., 2014). The hair on the scalp and body (chest, arm and leg) has been valued in the measurement of ethyl glucuronide (EtG) which is a direct alcohol marker in forensic and clinical toxicology (Pianta *et al.*, 2013). At the molecular level, studies have shown that hair can be analysed for their exposure to drugs and environmental pollutants (Wei *et al.*, 2013; Sen, 2010; Balíková 2005). In assessing the effect of hair care products, microscopic examination of hairs is important in the cosmetic industries (Kharin *et al*., 2009). In medicine similarly, microscopic hair analysis is used in the assessing dietary intakes (Rasmussen and Børsting, 2000), poisonous element levels (Kinova *et al*., 1988) skin diseases (Oien, 2009; Plozzer *et al*., 2000), osteopenia (low bone mineral density), hereditary osteoporosis and heart diseases (Mistry *et al*., 2010; Tobin and Paus, 2001).

2.10 Microscopic examination on hair

Hair identification is done with determination keys that are dependent on the shape, size, colour and profile of the hair. Also microscopic features such as medulla, cortex, and cuticle (Teerink, 2003) can be used for identification of hair. Identifying hair is challenging due to the presence of substantial difference affected by the type of species, gender of mammals, condition of the environment such as climate and nutrition and the region of the body the hair is derived from (Meyer *et al*., 2000). The complex nature of identifying hair is due to the various types of hair particular animal produces. Moreover the structural differences along with a hair strand and different animals can have hairs with the same structure (Marshall *et al*., 1977).

Hair examination is done for investigative purpose using the optical light microscope. The examination of hair requires two practices mainly; which are the identification of unknown hair and the association of the questioned hair with a hair of known origin (Deedrick, 2000). Before an examination, the first procedure is to verify whether its hair or fibre. Other relevant information includes the racial origin of the hair as well as the organism the hair was obtained from. Also, other details for assessment of hair include artificial alteration and how the hair was gotten from (whether pulled or fell off naturally). The features upon which hairs are compared include shape, form, diameter, pigmentation, medullation and scale characteristics, (Sen, 2010). Hair examination can be done macroscopically and microscopically. The macroscopic features can be seen with the eye and include form, curl and colour. Macroscopic examination of hair is followed by microscopic examination to provide more detail and information (Deedrick, 2000).

The optical light microscope provides a poor topographic resolution of the features of hair. The Transmission electron microscope gives a better resolution but is sometimes affected by spherical aberration which results in the formation of imperfect images. However many studies of the surface patterns and scale patterns of the cuticle has been done (Sahajpal *et al*., 2009).

In the absence of nuclear material, mitochondrial DNA has improved the array of tests for evaluating the relationship between unknown hair and a person. According to Houck and Budowle (2002), both molecular and microscopic hair analysis is important in forensic investigation. They also recommended that both methods can be used in the analysis of hair evidence when possible.

Moreover, a microscopic investigation has an added value of decreasing the time and the budget of mtDNA analysis as most of unknown hairs can be worked as fast as possible. Also, valued evidence can be gotten after microscopic examination of features not related to the subject of identity (for instance, forceful removal of hair) which is not feasible with mtDNA analysis (Houck and Budowle, 2002).

2.11 Morphological studies of hair in Ghana

Aboagye *et al*. (2014) studied the light microscopic morphology of indigenous Ghanaian African Hair from the facial and chest regions using male cadavers. Quantitative and qualitative features of hair such as hair shaft diameter, medullary diameters and cuticular scales were determined and compared between the face and chest regions. The results of the study showed that the microscopic and macroscopic regional differences were morphologically distinguishable. From the study, it was established that grey hairs were different from black hairs acquired from the similar body region of cadavers. For the first time, the study showed that grey hair had a greater shaft diameter for sideburn and chest hairs when compared with black hair in the same region.

Buame (2017, unpublished thesis) examined by light microscopy the morphology of scalp hair of Ashanti and Dagomba ethnic groups. The study was conducted in 400 students of Kwame Nkrumah University of Science and Technology (KNUST). The study showed that the morphological characteristics of the medulla such as medulla index, medulla diameter and hair shaft diameter of human hair cannot be used to differentiate Ashantis from Dagombas.

Kalmoni *et al*. (2019) examined hairs from the scalp, eyebrow, axilla and the pubic hair using the light microscope. The results of the study showed that hair shaft diameters increased in ascending order; eyebrow, scalp, axilla and pubic hair. The scale count per unit was higher in males than in females. The study recorded that the regular waved scale pattern was dominant in males while the irregular mosaic pattern was dominant in females.

Essel *et al*. (2019) researched on the microscopic characteristics of scalp hair subjected to cultural styling methods in Ghanaian African females. The study involved 96 indigenous Ghanaian females who gave 480 hairs which were analysed by the light microscopy. The samples were plucked from five different regions of the scalp which included the frontal, right temporal, left temporal, vertex and the occipital regions. The cultural styles included Afro (natural unstyled hair), natural styled (weaved or braided) and chemically relaxed hair. The shaft and medulla dimensions were measured as well as the cuticular scale features. Comparisons were made between the styling procedures and the regions of the scalp. From the study, the medulla was thickest in the Afro hair which correlated with the shaft diameter. Chemically treated hairs on the other hand had altered morphology which did not have these characteristics.

2.12 Scanning Electron Microscope (SEM) studies of hair

The SEM is a type of electron microscope that uses a focused beam of high energy electrons to create a range of signals on the surface of a solid material. The derived signals between the electron and the specimen provide information about it by scanning. This information includes external morphology, chemical composition, crystalline structure and orientation. The data of samples can be collected over the surface of at selected areas. A 2-Dimensional image is also generated which displays spatial variations (Goldstein, 2003).

Electrons accelerated in SEM have enough amount of kinetic energy. The energy produced is as a result different signals from electrons and sample interaction. The images from SEM are derived from secondary electrons, backscattered electrons for determination of crystalline structure and orientation of samples, characteristic X-ray for analyzing elemental and continuum x-rays, visible light and heat. Secondary electrons provide better morphology and topography of samples (Voutou and Stefanaki, 2008). The latter cited reference asserts that backscattered electrons are also good for analysis of multiphase material samples and escape the sample surface with the energy of greater or equal to 50eV. X-rays are generated when incident electrons collide with the electrons of the discrete orbitals of atoms in a sample. SEM is used because it is non-destructive and can analyse samples repeatedly (Goldstein, 2003).

According to former studies, Scanning Electron Microscopy (SEM) was used to study and record the features of hair samples. This also helped in facilitating taxonomic identification of fossil hair specimen (Reinhard and Bryant, 1992). The SEM techniques is better than other techniques in that, it gives a topographical resolution of the characteristics of the hair and also helps in elucidating the uniqueness of the hair surface structure. The SEM permits direct observation at high magnification allowing imaging of the specimen to give more detail (Teerink, 2003). This technique gives three-dimensional information, it is fast and relatively simple (Van den Broeck *et al*., 2001).

2.13 Albinism

Globally, about 1 out of 17, 000 persons (Gronskov *et al*., 2007) are affected by Albinism. This condition is inherited and is characterized by the reduction or absence of the melanin pigment. As a result of the mutation of one or several genes, albinism is a condition causing a lack of skin pigmentation in humans (Opara and Jiburum, 2010). It is a heterogeneous genetic disorder described by the absence of pigmentation in the eyes, hairs and skin (Oculocutaneous albinism) or only the eye (Ocular albinism) (Marcon and Maia, 2019). There is also syndromic albinism in which other clinical manifestations such as systemic pathologies occur.

In Persons with Albinism, there are normal quantity of cells in the epidermis and follicles but the melanin pigment is either totally or partially absent. The hypopigmentation of the hair, eyes and skin is due to the inability of individuals to produce the pigment. The variable phenotypes of persons with albinism are broad and range from pigmentation of hair skin and eyes to depigmentation (Bolognia *et al*., 2012). The melanin pigment is derived from tyrosine and it is synthesized primarily by the enzyme tyrosinase, P gene, tyrosinase-related protein 1 (TYRP1) and membrane-associated transporter protein (MATP). Each of these is mutated in the Oculocutaneous albinism (OCA) subtypes. For instance, persons with OCA are not capable of oxidizing tyrosine into dopa through tyrosinase (David, 2013). While OCA is associated with melanin production defects, syndromic albinism is associated with the defective formation and transport of melanosomes (Levin and Stroh, 2011; Scheinfeld, 2003).

Albinism is a disorder that can affect an individual of different social status as well as the country although there are different rates of incidence. Globally, the prevalence of albinism is 1 out of 20,000 persons. As cited by Marcon and Maia (2019), the United states record a prevalence of 1: 37, 000 whiles the highest prevalence is 6.3 per 1,000 population in the indigenous people of Cuna (Panama and Colombia). In Africa, the prevalence of albinism is 1 out of 4,000 people. Albinism is commoner among Blacks than other racial groups (Blackenberg, 2000). The prevalence in South Africa is 1 in 3,900 among Black South African population and 1 in 15,000 among White South African population. In Norway prevalence of albinism is 1 in 9,650, and 1 in 10,000 in Northern Ireland. The condition is much more prevalent in sub-Saharan Africa which ranges from 1 out of 2,000 to 1 out of 5, 000 persons (Hong *et al*., 2006) with estimates of 1 in 1,400 people being affected in Tanzania and prevalence as high as 1 in 1,000 reported for select populations in Zimbabwe. A study conducted in Namibia in 2011 recorded the highest national prevalence in Africa at 1 out of 1,755 as compared to the 2012 census in

Tanzania (1 out of 2,673) (Franklin *et al*., 2018). The prevalence rates in Zimbabwe, Tanzania and South Africa currently may be attributed to some traditional marriage practices as well as consanguinity. Limited geographic mobility can also be associated with present and future trends of the prevalence rates of albinism (Lund, 2005). According to Kwame Andrews Daklo, a member of the Ghana Association of Persons with Albinism (GAPA), a social worker and albino advocate with Engage now Africa, Ghana has more than 2000 persons with the condition (Thompson-Hernández, 2018)

In Ghana, persons with albinism are referred to as "ofiri djato" (Tau, 2014). Persons with albinism in Ghana, as compared to other parts of Africa, face little or no persecution. In most African societies albinism is considered as a disability and attitude towards these persons are as a result of lack of understanding, fear and lack of prejudice based on the appearance of a person with the condition (Mesaki, 2006). Many myths surround persons with albinism. These include they being born as a punishment for their parent's wrong, they being immortal, they being spirits, among others. These myths cause them to be seen as outcasts. In some east African countries, several persons with this condition are murdered for ritual purposes. It is believed that their body parts can be used to create a lot of wealth (Burke *et al*., 2014)

A person with albinism has to inherit two copies of the mutated gene from each parent. This is known clinically as a recessive inheritance. A person who has one copy of the mutated gene is considered a carrier since this individual has normal skin, hair or eye colour. Albinism is thought to be pleitropic since it has an effect on eye and skin colour and considered a carrier of the disorder. A feature common in all types of albinism is vision impairment with quite a number classified as "legally blind".

Albinism has no cure although it can be managed. The hypopigmentation of the skin of persons with albinism makes them vulnerable to sunlight, which induces skin lesions and cancers. Individuals who have this condition need to use protection from exposure to solar ultraviolet radiation (Emadi *et al*., 2017).

2.14 Classification of albinism

Albinism can be in a syndromic and non-syndromic form (Okamura and Suzuki, 2020). The syndromic albinism includes the Hemansky-Pudlak and Chediak-Higashi their subtypes. These syndromes show visual impairments and hypopigmentation with more severe pathological anomalies. Some of these pathologies include interstitial pulmonary fibrosis, hematologic changes and neurological problems (Möttönen *et al*., 2003). Also, albinism can be expressed as an exclusively ocular form that is Ocular albinism or foveal hypoplasia, optic nerve decussation defects and anterior segment dysgenesis syndrome (FHONDA) (King, 2006). Oculocutaneous albinism (OCA) is non-syndromic albinism and was initially described to have four main types (from OCA 1A and 1B to OCA 4) but till date, seven subtypes of OCA have been identified. The main cause of OCA is as a result of mutations in TYR, OCA2, TRYP1 and SLC45A2 (James *et al*., 2011; Zühlke *et al*., 2007). SLC24A5 and C10orf11 are new genes which have been recently discovered to be responsible for the cause of OCA6 and OCA7 respectively (Grønskov *et al*., 2013).

2.15 Symptoms of albinism

At birth, the following symptoms are apparent in persons with albinism. They include the absence of iris, hair and skin colour, lighter than normal skin and patchy skin colour (Nouri, 2008; Horobin, 2008). The following symptoms are associated with early childhood and they include Strabismus (crossed eyes), photophobia (light sensitivity), nystagmus (rapid eye movement) and vision problem or functional blindness (Sacharowitz, 2000).

2.16 Diagnosis of Albinism

Albinism can be diagnosed through genetic testing through most accurate DNA analysis. Testing is vital if there is a family history of albinism. Based on a person's appearance, doctors may diagnose a person with albinism due to eye, hair and skin colour. An electroretinogram can be performed by an ophthalmologist to detect vision problems associated with albinism (Gronskov, 2007).

2.17 Treatment of Albinism

Albinism cannot be cured but treatment is done to relieve symptoms. The treatment is related to the degree of a person's condition. Treatment includes the use of sunglasses with high ultraviolet protection to reduce light sensitivity, glasses to treat infertile nystagmus and to correct eyesight problems as well as the position of the eye, muscle surgery of the eye to correct abnormal eye movement and reducing sunburn risk by avoiding direct sun, using sunscreen with a high sun protection factor (SPF) and protecting the body with protective clothing (McGarry and Tong, 2013; Brodsky, 2010; Enderle, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study design

This study was a cross-sectional and observational, involving convenient sampling. It employed standard laboratory procedures using the Scanning electron microscope to examine hairs from persons with and without albinism. Morphometric methods were employed to quantitatively assess hair variables for comparative purposes between the two populations sampled.

3.2 Ethical consideration

Approval for the study was sought from the Ethical and Protocol Review Committee, College of Health Sciences, University of Ghana; Korle-Bu Campus (Protocol ID. No.: CHS-Et/M2 – 5.8/2019/2020). Permission was also obtained from the Ghana Association of Persons with Albinism (GAPA), who gave access to their membership from whom volunteers were elicited. Study participants were made to give informed consent to their participation by completing a consent form after the purpose and risks had been explained to them.

3.3 Study site

The study was conducted in Accra in the Greater Accra region of Ghana. Accra is the largest city and the capital of the Republic of Ghana and located in the Greater Accra Region. It covers an area of 225.67km^2 with an estimated population of 2.27 million as of 2012 (Ghana Statistical Service, 2012). It is the economic and cultural centre of the Greater Accra region which is one of the largest and fastest-growing areas in West Africa with an annual growth rate of about 4.3% (Ghana Statistical Service, 2010). According to statistics from GAPA, members registered with the Association are estimated to be 2,500 nationwide. In Accra as at the year 2019, Persons with albinism that were registered with the association were 350. This study site was selected because Persons with Albinism in Accra belong to the Ghana Association of Persons with Albinism (GAPA) from which permission was sought for the collection of samples.

3.4 Sample size determination

The sample size was determined using this formula based on the nature of the study design and statistical consideration of the study population;

$n = \frac{z^{2(p)(1-p)}}{d^2}$ (Klufio, 2003)

Where z is the standard score at 95% confidence interval = 1.96

p is the expected proportion in population-based on previous study or pilot study = 0.20 (Kalmoni *et al.*, 2019)

d is precision(corresponding to effect size) = 0.1

n is the sample size = 60

3.5 Subjects and study population

Sixty participants (60) were recruited from the study area. The 60 participants included 30 persons with albinism (PWA) and 30 persons without albinism (PWO). The participants included 15 males and 15 females for each of the two groups. The participants for both groups were sex and age-matched. PWAs were recruited from members of GAPA at their head office located in Adabraka. PWOs were recruited from students from the University of Ghana. The study participants were screened after questionnaires had been administered to determine their ancestry (Appendix two). The ancestry of study participants was determined by tracing back to two familial generations who were native Ghanaians.

3.6 Inclusion criteria

Participants were 18 years and above. The reason for the exclusion of persons below 18 years was because of the delicate skins of PWAs, it was advisable to include persons above the age of 18 years to prevent causing too much pain to participants. Both PWAs and PWOs signed a consent form to participate in the study. PWAs manifesting as hypopigmentation of the skin and hair and recognized members of the Accra branch of GAPA were included in the study. PWO who had black hair were included in the study. PWAs and PWOs whose parents and grandparents were all native Ghanaians were included in the study.

3.7 Exclusion criteria

Members of GAPA aged below 18 years were excluded. Persons with albinism but who had normal skin and hair pigmentation were excluded from the study. Persons with skin/hair hypopigmentation but who declined consent by refusing to complete forms were excluded. Persons without Albinism who had grey hair or had dyed their hair were excluded from the study. PWO who refused to complete consent forms were also excluded from the study. PWA and PWOs whose parents and/or grandparents were not native Ghanaians were excluded from the study.

3.8 Participant selection

Volunteers were solicited from GAPA after permission has been sought from their Executive Director. Persons with Albinism who consented as indicated above were recruited at their meeting centre where hair samples were taken. The meetings of GAPA come off every quarter of the year where members are present. In the case where individuals cannot make it to the meeting centre, an advocate who is a person with Albinism helped with contacting individuals on phone so that samples could be taken at home. Participants were engaged in a conversation with the help of the advocate to enlighten them on the research work and its relevance to their association. PWOs were selected at random. Participants were engaged in a conversation and the research work was explained into detail with its relevance. Interested persons were given a consent form (Appendix one) to fill and sign. Upon satisfying the inclusion criteria, participants were recruited.

3.9 Sample collection

A hair strand was plucked randomly from five regions of the scalp identified in previous studies (Essel *et al*., 2019). The regions of the scalp are; frontal, vertex, left temporal, right temporal and occipital regions. The hairs were plucked using a pair of cosmetologist's tweezers. The hair strands plucked from each scalp region were kept in different Ziploc bags and labelled based on areas of the scalp and code for the participant. Each strand in an envelope was allocated with a specific identification number. The identification number was used to ensure that the hair strands plucked from different individuals do not mix up and also to maintain the confidentiality of the participants. Three hundred (300) hair strands were obtained from sixty (60) participants categorized into 30 (15 males and 15 females) persons with Albinism and 30(15 males and 15 females).

3.10 Preparation of hair for microscopy

The hair samples that were plucked with the pair of cosmetologist tweezers were mounted on specimen stubs with double-stick cellophane tape. The surface of the hair samples was coated with gold using a Sparta coater (TED PELLA, INC 4595 Mountain lakes Bivd, Redding, CA 96003, USA). Long hairs were divided into proximal (100 µm from the root), middle (100 µm mid-way of the remaining strand of the hair) and distal (100 µm from the tip) and mounted on aluminium stubs. The hairs were scanned using the Scanning Electron Microscope

(PHENOMWORLD 24VDC/ 12.5 Amp. Max, Netherlands) from root to tip to observe the surface topological characteristics and digital images were captured. SEM-EDS analysis was done on all hair samples to determine the elemental components of the hairs of PWA and PWO.

3.11 Structural Features of examined hairs

Morphological features were both qualitative and quantitative. Quantitative features measured included Hair Shaft Diameter (HSD), Mean Scale Count (MSC) and Interval between Scale Margins (ISM). Qualitative features examined included scale pattern, type of scale edge (structure of scale margin) and distance between scale margins.

3.11.1 Hair Shaft Diameter

Hair Shaft Diameter (HSD), was measured as averages from the diameters of three different parts (proximal middle and distal) of the hair strand using Image J software. All the measurements were done in micrometres (µm). Figure 13 shows how the hair shaft diameter was measured.

3.11.2 Mean Scale Count and Interval between scale margins

Three micrographs each were selected from the proximal and distal portions of the hair. They were assessed quantitatively for the interval between scale margins (ISM) and mean scale count (MSC). The Image J software was used to quantify the interval between two scales at ten (10) randomly selected points parallel to the longitudinal axis of hair strand on each scanning electron micrograph. The averages were calculated. For the mean scale count, the number of scale edges was counted at six different sites across the width of each scanning electron micrographs. The six counts were done for three selected micrographs and the average was calculated. Figure 14 shows how the MSC and ISM were counted and measured respectively.

3.11.3 Qualitative features

According to Ryder (1973) patterns of scales were evaluated based on three criteria. The topography of the hair scale margins was determined as smooth, crenate (having shallow indentations), or rippled (having deep indentations). The vertical distance between the scale margins was determined as close, distant, or near (which is intermediate between close and distant). The scale pattern was determined as mosaic, which was regular (in which visible parts of the scales are of similar size), or irregular (in which they varied), or waved, which was either regular or irregular in shape, waved patterns could occur with mosaic to give combinations such as irregular/regular-waved mosaic (Mistry *et al.*, 2010).

The tips of the hair samples were evaluated based on four criteria; pointed, razor cut tip, blunt and fibrillated. The roots of the hair samples were also analysed based on whether they were in the anagen, catagen or telogen phase of growth. The roots were staged based on previous studies done in Ghana.

3.12 Statistical analysis

Data was captured using Microsoft excel 2010 and results were analysed. Data were expressed as means and standard deviations. Statistical significance of the variation between group means was done by one-way analysis of variance (ANOVA) at a 95% confidence interval and posthoc independent t-tests. All differences with probability (p) value less than 0.05 was considered statistically significant.

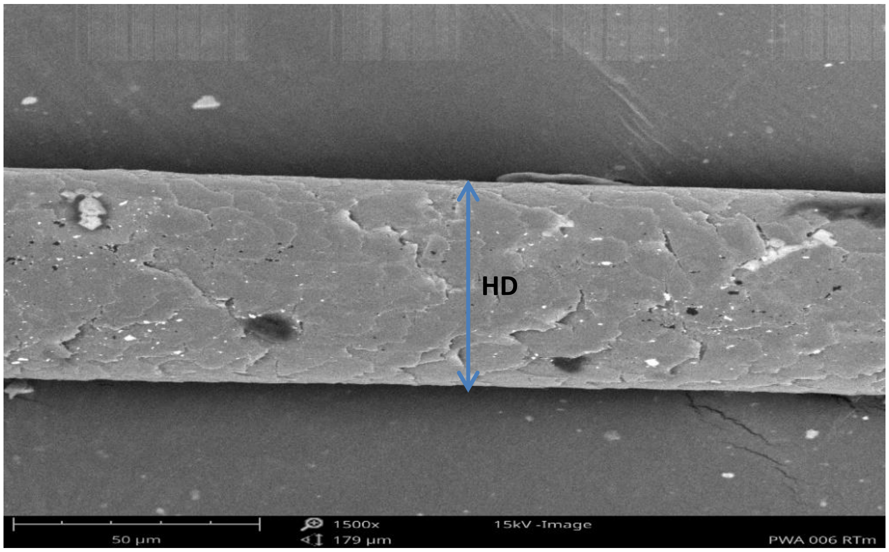


Figure 13: Scanning electron micrograph of a hair strand, the double arrow indicates the hair shaft diameter (HD).

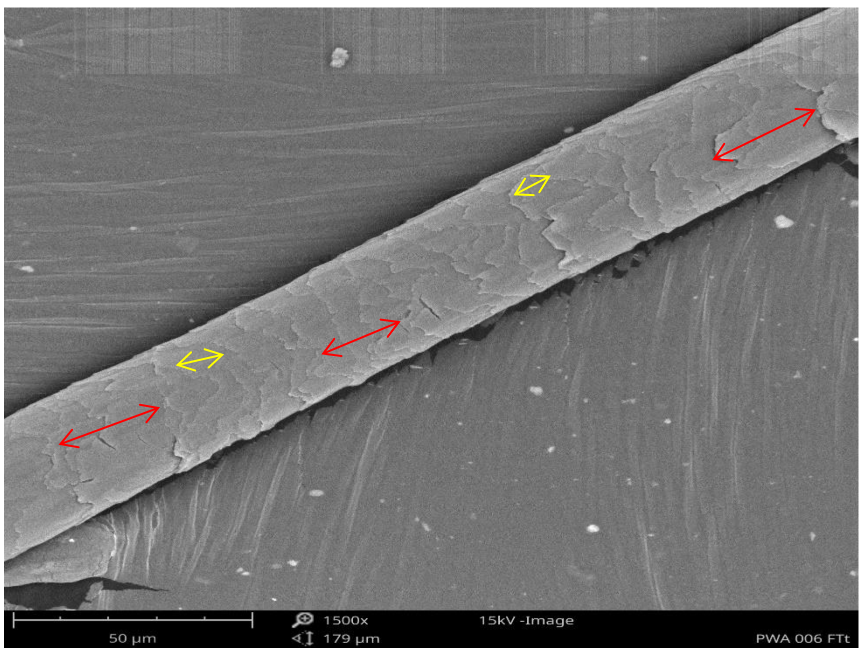


Figure 14: Scanning electron micrograph of hair strand showing scale topography. Illustrated are two qualitative features assessed. The red double head arrow represents scale counts. The yellow double head arrow shows the interval between scale margins.

CHAPTER FOUR

4.0 RESULTS

4.1 Age distribution of Participants

The mean age in years for study participants were 30.73 years (SD= 8.53), 24.2 years (SD= 6.61), 31.3 years (SD= 8.07), 28.87 (SD= 4.91), 29.4 years (SD =7.70) and 28.9 years (SD= 6.54) for male PWA, female PWA with natural styled hair, female PWA with permed hair, male PWO, female PWO with natural styled hair and female PWO with permed hair respectively (Table 2). A Mann-Whitney test showed no significant difference between ages of male PWA and PWO (p=0.6225), female PWA and PWO with natural styled hair (0.1508) and female PWA and PWO with permed hair (p=0.8192).

Table 2: Mean age of study participants

Hair style	N	Mean Age (yrs)	Standard Deviation	SE Mean	Range
Male PWA	15	30.73	8.53	2.2	20-45
Female PWA with natural styled hair	5	24.20	6.61	2.96	19-35
Female PWA with permed hair	10	31.30	8.07	2.55	21-45
Male PWO	15	28.87	4.91	1.27	22-40
Female PWO with natural styled hair	5	29.40	7.70	3.44	22-39
Female PWO with permed hair	10	28.9	6.54	2.07	19-40

4.2 SEM-EDS analysis of hairs

Thirteen different elements were analysed employing the EDS analysis. The elements were Carbon (C), Nitrogen (N), Oxygen (O), Phosphorus (P), Potassium(K), Aluminium (Al), Magnesium (Mg), Boron (B), Sulphur (S), Chlorine (C), Sodium (Na), Silicon (S) and Calcium (Ca).

Table 3 shows the means and standard deviations (SD) of the mean weight percentage of the analysed elements of hairs from all five scalp regions for the two groups of study participants. In the five scalp regions of both PWA and PWO, Carbon (C) had the highest weight percentage followed by Oxygen (O) and Nitrogen (N). In PWA, Boron was the fourth highest element recorded but in PWO, Sulphur (S) was the fourth highest element recorded in the hair shaft. In all the five regions of the scalp, there was a significant variation between the mean weight percentages of Boron (B) in both groups ($p < 0.0001$). Magnesium (Mg) was the least in weight percentage for both PWO and PWA.

Table 3: Statistics of distribution of chemical elements in scalp hairs of PWA and PWO assessed by SEM-EDS analysis

	Frontal		Left temporal		Occipital		Right Temporal		Vertex	
	PWA	PWO	PWA	PWO	PWA	PWO	PWA	PWO	PWA	PWO
Element	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)	Mean± SD (weight %)
C	48.27 ± 2.60	47.47 ± 4.76	49.85 ± 3.44*	47.88 ± 4.60*	50.12 ± 3.89*	48.06 ± 3.91*	48.44 ± 3.22	48.18 ± 4.11	50.20 ± 3.56	48.69 ± 4.57
O	18.43 ± 2.87*	22.88 ± 4.08*	18.36 ± 3.01*	22.47 ± 4.33*	17.99 ± 3.50*	22.28 ± 3.29*	17.91 ± 3.21	22.15 ± 4.32*	17.63 ± 2.79*	21.70 ± 3.95*
N	17.63 ± 2.83*	20.68 ± 3.57*	17.15 ± 2.65*	20.63 ± 3.87*	16.79 ± 2.62*	20.83 ± 3.32*	17.66 ± 3.02	20.29 ± 3.49	17.32 ± 3.29*	20.26 ± 2.49*
S	4.63 ± 2.50	5.52 ± 2.49	4.53 ± 1.83	5.24 ± 2.36	4.78 ± 1.84	5.84 ± 2.27	5.02 ± 3.05	5.64 ± 2.51	4.38 ± 1.69*	6.26 ± 3.67*
Cl	0.52 ± 0.48	0.51 ± 0.45	0.57 ± 0.39	0.61 ± 0.48	0.54 ± 0.38	0.74 ± 1.02	0.70 ± 0.40	0.69 ± 0.53	0.55 ± 0.51	0.75 ± 0.69
Al	0.22 ± 0.26*	0.11 ± 0.22*	0.14 ± 0.15*	0.06 ± 0.12*	0.19 ± 0.21*	0.18 ± 0.57*	0.20 ± 0.65	0.20 ± 0.65	0.20 ± 0.31*	0.03 ± 0.09*
P	0.45 ± 0.35	0.43 ± 0.40	0.36 ± 0.24	0.45 ± 0.31	0.44 ± 0.26	0.45 ± 0.41	0.39 ± 0.17	0.49 ± 0.35	0.49 ± 0.41	0.50 ± 0.57
K	0.33 ± 0.33	0.48 ± 0.43	0.23 ± 0.18	0.34 ± 0.29	0.30 ± 0.32	0.38 ± 0.40	0.24 ± 0.22	0.46 ± 0.55	0.36 ± 0.49	0.37 ± 0.51
Na	0.16 ± 0.17	0.13 ± 0.20	0.10 ± 0.12	0.10 ± 0.21	0.13 ± 0.16*	0.11 ± 0.25*	0.19 ± 0.22*	0.06 ± 0.12*	0.13 ± 0.19*	0.11 ± 0.21*
Si	0.32 ± 0.38	0.31 ± 0.43	0.26 ± 0.23	0.37 ± 0.87	0.33 ± 0.34	0.20 ± 0.21	0.26 ± 0.16*	0.18 ± 0.25*	0.28 ± 0.25*	0.20 ± 0.34*
B	8.73 ± 2.03*	1.56 ± 3.19*	8.27 ± 1.42*	1.65 ± 3.49*	8.19 ± 1.67*	1.46 ± 3.00*	8.68 ± 1.69*	1.86 ± 3.86*	8.33 ± 1.55*	1.45 ± 2.96*
Mg	0.10 ± 0.18	0.09 ± 0.22	0.06 ± 0.10*	0.11 ± 0.55*	0.07 ± 0.20*	0.01 ± 0.04*	0.07 ± 0.12*	0.02 ± 0.06*	0.05 ± 0.07*	0.04 ± 0.15 *
Ca	0.20 ± 0.37	0.43 ± 1.00	0.19 ± 0.34	0.30 ± 0.89	0.19 ± 0.56	0.15 ± 0.38	0.12 ± 0.18	0.27 ± 0.72	0.14 ± 0.35	0.32 ± 0.65

Means with superscript (*) show significant difference at $p<0.05$

4.3 Hair Shaft Diameter

Diameter measurements were taken for both males and females for both groups. The mean shaft diameters of the hairs were obtained from the diameters of the three portions of the hair shaft (proximal, middle, and distal) for both groups.

The regional mean shaft diameters of hairs obtained from the collation of diameters of the three portions (proximal, middle, and distal) of each hair shaft for the hairstyle groups are shown in Table 4. For Male PWA, the mean of hair diameter (standard deviation) were as follows: FT, 66.97µm (14.61), LT, 74.94µm (20.26), OC, 59.13µm (8.84), RT, 75.02µm (15.23), VT, 69.53µm (16.74) (Table 4). For male PWO, the mean hair diameter (standard deviation) were FT, 74.67µm (18.45), LT, 83.87µm (18.85), OC, 73.49µm (11.61), RT, 75.58µm (11.10), VT, 81.23µm (15.92) (Table 4). For female PWA who had natural styled hair, the mean hair diameter (standard deviation) were FT, 70.73µm (19.27), LT, 60.61µm (19.71), OC, 61.84µm (10.9), RT, 60.91µm (23.97), VT, 56.83µm (20.27). For female PWO who had natural styled hair, the mean hair diameter (standard deviation) were FT, 65.63µm (17.9), LT, 57.57µm (11.63), OC, 58.62µm (16.73), RT, 74.95µm (9.5), VT, 71.18µm (12.66) (Table4). For female PWA who had permed hair, the mean hair diameter (standard deviation) were FT, 77.38µm (14.36), LT, 68.21µm (15.48), OC, 67.22µm (15.97), RT, 67.53µm (13.49), VT,78.67µm (19.89) (Table). For female PWO who had permed hair, the mean hair diameter (standard deviation) were FT, 61.63µm (15.39), LT, 68.45µm (20.89), OC, 65µm (11.16), RT, 58.98µm (17.59), VT,77.8µm (11.33) (Table 4). Comparison of the mean shaft diameters between PWA and PWO in all the various scalp regions showed no significant differences except for the OC region of male PWA and PWO ($p=0.0005$) (Table 4).

In males PWA and PWO where all the hairs were natural unstyled hairs, there was no significant difference between the hair diameters of all the scalp regions except for the OC region which showed a difference of p=0.0049 and p=0.001 in the proximal and middle portions of the hair shaft respectively. In females PWA and PWO who had natural styled hair, there was no variation between the means of all the scalp region hairs except for the OC region of the middle portion of the hair shaft which showed a difference of p=0.0154 in both groups. In female PWA and PWO who had chemically treated (permed) hair, there was no variation between the means of all the scalp region hairs except for the FT region of the scalp which showed a significant difference of p=0.0039 in the distal portion of the hair shaft.

Table 4: Regional hair shaft diameters for both PWA and PWO

		PWA				PWO			
Sex	Region of the scalp	Mean (µm)	SE mean	SD	Range	Mean (µm)	SE mean	SD	Range
Male	FT	66.97	3.77	14.61	44.91 – 88.52	74.67	4.76	18.45	48.67 – 106.30
	LT	74.94	5.23	20.26	37.93 – 104.30	83.87	4.87	18.85	53.49 – 122.00
	OC	59.13	2.28	8.84	45.94 – 79.19	73.49	3.00	11.61	54.62 – 94.71
	RT	75.02	3.93	15.23	46.92 – 103.20	75.58	2.87	11.10	61.37 – 100.10
	VT	69.53	4.32	16.74	45.12 – 95.66	81.23	4.11	15.92	50.98 – 102.50
Female (Natural styled hair)	FT	70.73	8.62	19.27	39.49 – 89.83	65.63	8.00	17.90	46.50 – 95.03
	LT	60.61	8.82	19.71	33.67 – 88.98	57.57	5.20	11.63	38.43 – 67.60
	OC	61.84	4.87	10.90	47.66 – 76.89	58.62	7.48	16.73	34.59 – 78.84
	RT	60.91	10.72	23.97	38.56 – 101.60	74.95	4.25	9.50	60.99 – 85.96
	VT	56.83	9.07	20.27	27.00 – 78.15	71.18	5.66	12.66	54.92 – 84.34
Female (Permed hair)	FT	77.38	4.54	14.36	56.22 – 95.73	61.63	4.87	15.39	30.92 – 76.90
	LT	68.21	4.90	15.48	40.10 – 88.10	68.45	6.61	20.89	29.26 – 102.90
	OC	67.22	5.05	15.97	39.40 – 90.31	65.00	3.56	11.16	36.23 – 77.02
	RT	67.53	4.27	13.49	45.45 – 91.69	58.93	5.56	17.59	26.12 – 76.59
	VT	78.67	6.29	19.89	49.18 – 109.50	77.80	3.58	11.33	59.22 – 96.14

4.4 Scale Characteristics

The proximal and distal segments of the hair shaft were considered. Two quantitative variables, Mean Scale count and the interval between scale margins were assessed. Three qualitative hair features, namely; the scale pattern, the geometry of the scale margins, and the subjective distance between the scale margins were described.

4.4.1 Mean Scale Count (MSC)

In the proximal part of the hair shaft, the mean scale count showed no statistical differences among hairs from the five scalp regions of male PWA and PWO. Similarly, in female PWA and PWO with natural styled hair, mean scale counts of the hairs from the studied scalp regions showed no significant differences. In female PWA and PWA with permed hair, there were no significant mean scale count differences among hairs from the various scalp regions except for the FT region (p=0.0481) (Table 5).

In the distal part of the hair shaft, mean scale counts showed significant differences between hairs from the LT region (p=0.0373) and OC region (p=0.0186) of male PWA and PWO. In female PWA and PWO with natural styled hair, there were significant differences between FT region of the scalp (p=0.0268), LT region (p=0.033) and OC region (p=0.0056). In female PWA and PWO with permed hair, significant differences between mean scale counts were obtained for hairs from the FT (p=0.0367), LT (p=0.0305) and VT (p=0.0302) regions of the scalp (Table 6).

Table 5: Mean scale count per 1 cm of proximal hair shaft for PWA and PWO

		PWA				PWO			
Sex	Region of the scalp	Mean	SEMean	SD	Range	Mean	SEMean	SD	Range
Male	FT	1.49	0.10	0.37	1.00 – 2.00	1.42	0.06	0.25	1.00 – 1.75
	LT	1.43	0.10	0.39	1.00 – 2.00	1.47	0.07	0.27	1.06 – 2.00
	OC	1.47	0.11	0.42	1.00 – 2.00	1.42	0.05	0.20	1.17 – 1.72
	RT	1.60	0.10	0.39	1.00 – 2.00	1.39	0.06	0.25	1.00 – 1.83
	VT	1.58	0.10	0.39	1.08 – 2.00	1.42	0.07	0.28	1.00 – 1.92
Female (Natural styled hair)	FT	1.53	0.08	0.37	1.00 – 2.00	1.40	0.05	0.23	1.00 – 1.75
	LT	1.43	0.08	0.36	1.00 – 2.00	1.47	0.06	0.26	1.06 – 2.00
	OC	1.45	0.09	0.42	1.00 – 2.00	1.39	0.05	0.21	1.00 – 1.72
	RT	1.51	0.09	0.39	1.00 – 2.00	1.35	0.05	0.23	1.00 – 1.83
	VT	1.56	0.08	0.36	1.08 – 2.00	1.38	0.06	0.26	1.00 – 1.92
Female (Permed hair)	FT	1.58	0.21	0.65	0 – 2.00	1.31	0.08	0.26	1.00 – 1.83
	LT	1.31	0.25	0.78	0 – 2.33	1.19	0.15	0.46	0 – 1.72
	OC	1.40	0.20	0.62	0 – 2.20	1.32	0.08	0.26	1.00 – 1.83
	RT	1.38	0.18	0.57	0 – 1.89	1.06	0.19	0.61	0 – 1.83
	VT	1.58	0.12	0.38	1.00 – 2.00	1.32	0.06	0.20	1.00 – 1.78

Table 6: Mean scale count per 1 cm of distal hair shaft for PWA and PWO

		PWA				PWO			
Sex	Region of the scalp	Mean	SEMean	SD	Range	Mean	SEMean	SD	Range
Male	FT	1.76	0.12	0.48	1.00 – 2.83	1.43	0.13	0.52	0 – 2.00
	LT	1.70	0.11	0.41	1.00 – 2.33	1.36	0.10	0.37	1.00 – 2.00
	OC	1.77	0.09	0.35	1.00 – 2.16	1.47	0.08	0.33	1.00 – 2.00
	RT	1.84	0.11	0.43	1.08 – 2.67	1.60	0.09	0.36	1.00 – 2.30
	VT	1.70	0.08	0.32	1.17 – 2.17	1.48	0.10	0.38	1.00 – 2.00
Female (Natural styled hair)	FT	1.86	0.11	0.50	1.00 – 3.00	1.46	0.11	0.50	0 – 2.00
	LT	1.64	0.09	0.39	1.00 – 2.33	1.37	0.08	0.34	1.00 – 2.00
	OC	1.77	0.07	0.32	1.00 – 2.16	1.47	0.07	0.32	1.00 – 2.00
	RT	1.74	0.10	0.43	1.08 – 2.67	1.56	0.08	0.35	1.00 – 2.30
	VT	1.67	0.06	0.29	1.17 – 2.17	1.46	0.08	0.37	1.00 – 2.00
Female (Permed hair)	FT	1.59	0.19	0.60	0 – 2.00	1.23	0.17	0.54	0 – 2.00
	LT	1.72	0.12	0.38	1.00 – 2.33	1.09	0.20	0.64	0 – 1.83
	OC	1.37	0.25	0.80	0 – 2.33	1.23	0.16	0.52	0 – 1.83
	RT	1.11	0.32	1.02	0 – 2.58	1.01	0.18	0.57	0 – 1.83
	VT	1.51	0.19	0.61	0 – 2.00	1.32	0.06	0.20	1.00 – 1.50

4.4.2 Interval between scale margins (ISM)

In the proximal part of the hair shaft, the ISM was significantly different between male PWA and PWO only in the FT region (p=0.001) out of the five scalp regions. In females the ISM of hairs from the various scalp regions yielded no significant differences between PWA and PWO with natural styled or permed hair. (Table 7)

In the distal part of the hair shaft except for the OC region (p=0.0365) of the scalp, the ISM showed no significant differences between male PWA and PWO. Whereas the ISM of hairs from the various scalp regions had no significant differences between female PWA and PWO with natural styled hair; there were statistical differences between female PWA and PWO with permed hair for LT (p=0.0181) and VT (p=0.0354) regions of the scalp (Table 8).

Table 7: Interval between scale margin for the proximal hair shaft in albinos (PWA) and non-albinos (PWO)

		PWA				PWO			
Sex	Region of the scalp	Mean (µm)	SE mean	SD	Range	Mean (µm)	SE mean	SD	Range
Male	FT	11.58	0.59	2.29	7.96 – 16.18	9.03	0.34	1.33	6.91 – 10.84
	LT	9.91	0.48	1.85	7.26 – 13.57	9.31	0.43	1.68	7.08 – 13.68
	OC	9.33	0.25	0.98	7.76 – 11.34	8.69	0.33	1.28	6.37 – 10.96
	RT	9.82	0.36	1.41	7.72 – 12.77	8.93	0.17	0.67	7.73 – 10.01
	VT	10.05	0.42	1.64	7.62 – 13.60	8.80	0.41	1.58	6.23 – 11.90
Female (Natural styled hair)	FT	10.86	0.53	2.38	7.71 – 16.18	8.91	0.30	1.35	6.91 – 11.12
	LT	10.13	0.45	2.02	7.26 – 14.92	9.27	0.33	1.46	7.08 – 13.68
	OC	9.59	0.30	1.34	7.76 – 12.79	8.92	0.33	1.49	6.37 – 12.58
	RT	9.89	0.33	1.48	7.72 – 12.77	8.84	0.16	0.73	7.31 – 10.01
	VT	9.95	0.32	1.44	7.62 – 13.60	9.18	0.41	1.83	6.23 – 12.73
Female (Permed hair)	FT	8.44	1.09	3.43	0 – 13.71	8.68	0.27	0.85	7.66 – 10.50
	LT	8.65	1.49	4.72	0 – 13.14	8.93	1.09	3.46	0 – 11.94
	OC	9.04	1.07	3.39	0 – 11.84	8.54	0.39	1.22	7.03 – 10.82
	RT	6.36	1.09	3.46	0 – 9.06	10.16	1.35	4.26	0 – 15.28
	VT	9.74	0.74	2.33	6.76 – 13.74	9.32	0.38	1.20	7.17 – 11.24

Table 8: Interval between scale margin (ISM) for the distal hair shaft albinos (PWA) and non-albinos (PWO)

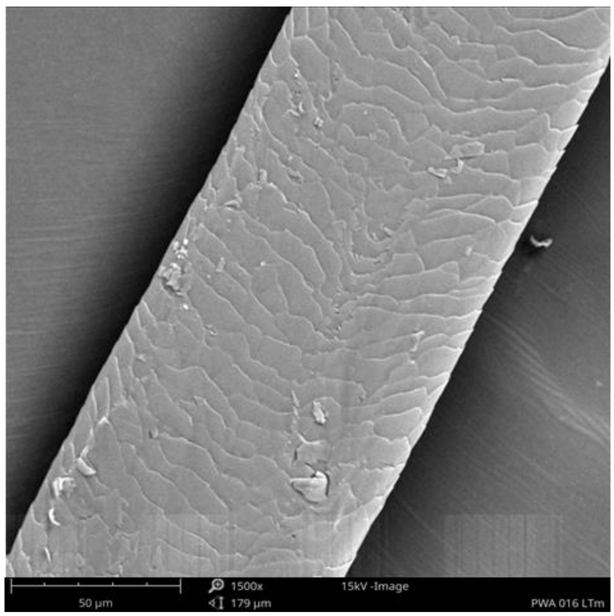
		PWA				PWO			
Sex	Region of the scalp	Mean (µm)	SE mean	SD	Range	Mean (µm)	SE mean	SD	Range
Male	FT	10.73	0.85	3.29	7.04 – 19.13	8.50	0.73	2.83	0 – 11.75
	LT	9.17	0.81	3.15	0 – 13.32	8.61	0.36	1.39	5.67 – 10.92
	OC	10.14	0.42	1.64	7.06 – 13.75	8.97	0.27	1.06	6.92 – 10.89
	RT	9.41	0.46	1.77	5.96 – 11.88	8.52	0.37	1.43	5.07 – 10.20
	VT	9.44	0.70	2.70	5.33 – 16.19	9.69	0.33	1.29	7.79 – 12.19
Female (Natural styled hair)	FT	10.40	0.67	2.99	7.04 – 19.13	8.98	0.61	2.75	0 – 12.72
	LT	9.41	0.63	2.80	0 – 13.32	8.68	0.31	1.38	5.67 – 10.92
	OC	10.01	0.35	1.57	7.06 – 13.75	8.76	0.25	1.14	6.45 – 10.89
	RT	9.33	0.36	1.59	5.96 – 11.88	8.75	0.31	1.36	5.07 – 10.61
	VT	9.65	0.55	2.44	5.33 – 16.19	9.47	0.28	1.27	7.79 – 12.19
Female (Permed hair)	FT	9.03	1.06	3.36	0 – 11.52	8.37	1.09	3.46	0 – 12.58
	LT	10.94	0.91	2.87	8.36 – 18.09	7.02	1.26	3.98	0 – 11.07
	OC	6.43	1.53	4.83	0 – 12.59	7.53	0.91	2.88	0 – 9.90
	RT	5.62	1.61	5.10	0 – 12.14	7.39	1.30	4.11	0 – 10.98
	VT	10.62	1.54	4.86	0 – 18.15	8.24	0.37	1.17	6.68 – 10.31

4.4.3 Scale patterns

The scale patterns were categorized into Regular mosaic, irregular mosaic, regular wave, and irregular wave for both the proximal and distal parts of the hair shaft (illustrated in Figures 15-20). For male PWA, in the proximal part of the hair shaft, the regular mosaic pattern was highest in occurrence (36/75, or 48%) followed by the regular waved pattern (26/75, or 36.67%), then irregular mosaic (8/75, or 10.67%) with irregular waved pattern (5/75, or 6.67%) being the least. For the proximal hair shaft of male PWO, regular waved scale pattern (36/75, or 48%) was highest, followed by the regular mosaic (35/75, or 46.67%). The distal hair shaft showed the highest occurring scale pattern as irregular waved for both male PWA (71/75, or 94.67%) and PWO (69/75, or 92%). In female PWA who had natural styled hair, the proximal shaft displayed the highest prevalent scale pattern was regular waved (11/25, or 44%) pattern followed by regular mosaic pattern (10/25, or 40%). In female PWO who had natural styled, in the proximal shaft, the highest occurring scale pattern was regular mosaic (13/25, or 52%), followed by the regular waved pattern (6/25, or 24%). In both female PWA and PWO who had natural styled hair, the distal hair shaft showed the highest scale pattern of irregular waved (PWA, 25/25 or 100%); PWO, 22/25 or 88%)). In female PWA who had permed hair, the proximal portion of the hair shaft showed the highest prevalent scale pattern of regular mosaic (24/50, or 48%), followed by regular waved pattern (14/50, or 28%). In female PWO who had permed hair, the proximal shaft showed the highest occurring scale pattern as regular waved (20/50, or 40%), followed by regular mosaic (16/50, or 32%).

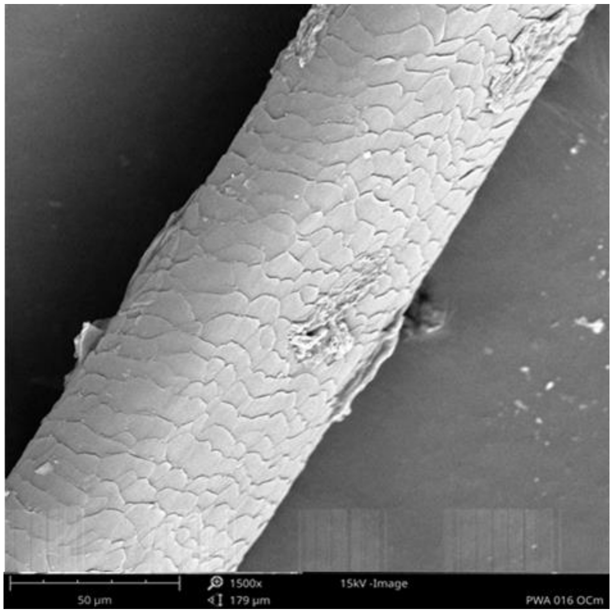
In proximal shafts of hair, Chi square test showed that there was no significant variation between the scale patterns of Male PWA and PWO (p=0.0871), female PWA and PWO with natural styled hair (p=0.4134) and female PWA and PWO with permed hair (p=0.2836). In distal shafts of hair, Chi square test showed that there was no significant variation between the scale patterns of Male PWA and PWO (p= 0.8373), female PWA and PWO with natural styled hair and female PWA and PWO with permed hair (p=0.2401). Figures 21, 22, and 23 show the numbers of hairs exhibiting various scale patterns for samples studied.

a. Proximal



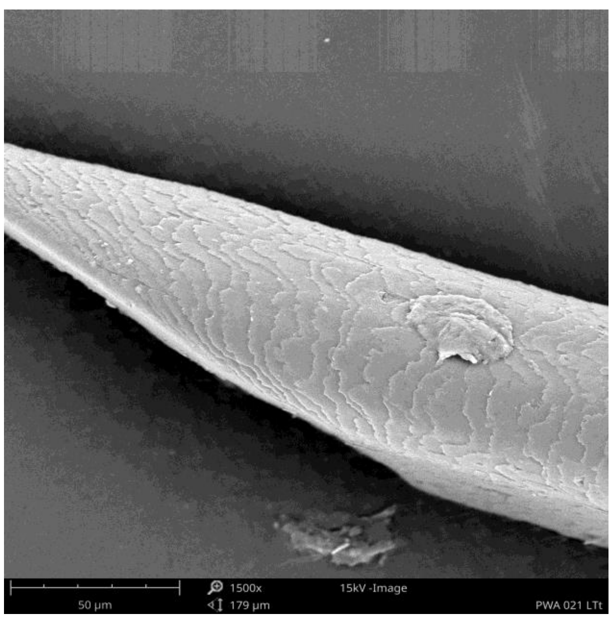
Regular waved, smooth, near

b. Proximal



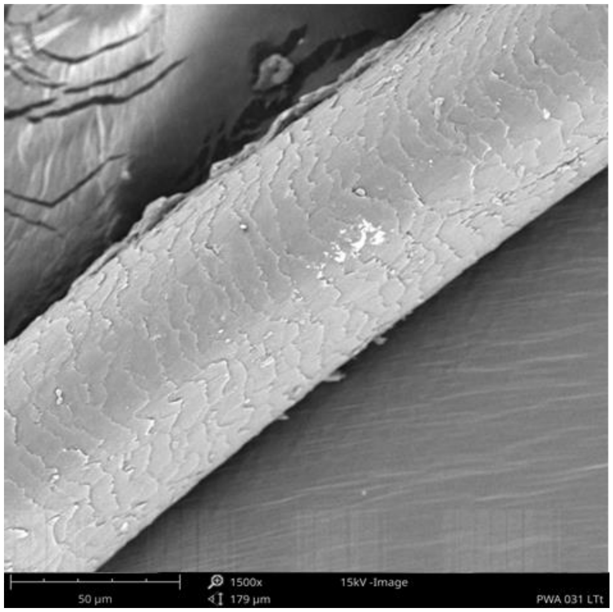
Regular mosaic, smooth, near

c. Distal



Irregular waved, rippled, close

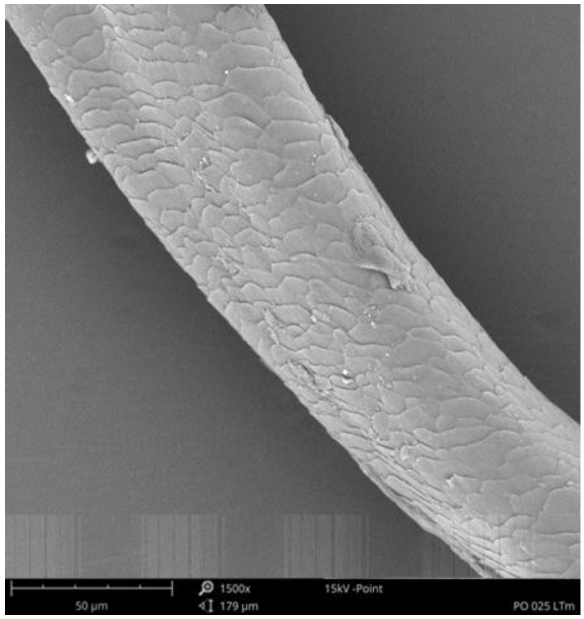
d. Distal



Irregular waved, rippled, near

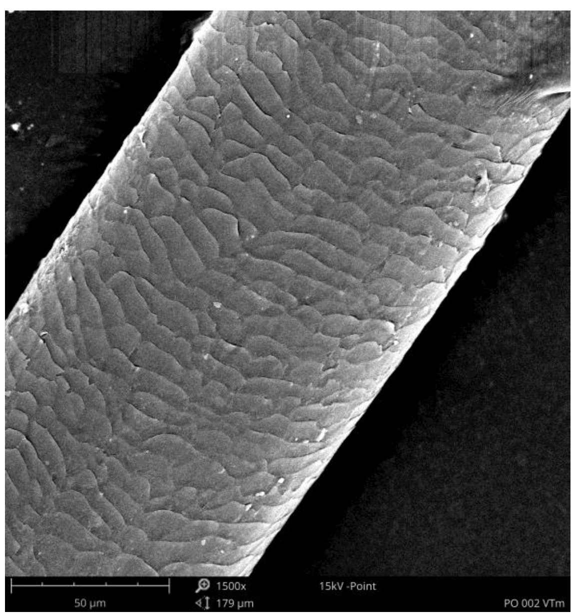
Figure 15 (a-d): Scanning electron micrographs of representative samples of proximal (a & b) and distal (c & d) hairs illustrating scale patterns. Samples were from male PWA. Magnification is indicated by the scale bar generated by the SEM.

a. Proximal



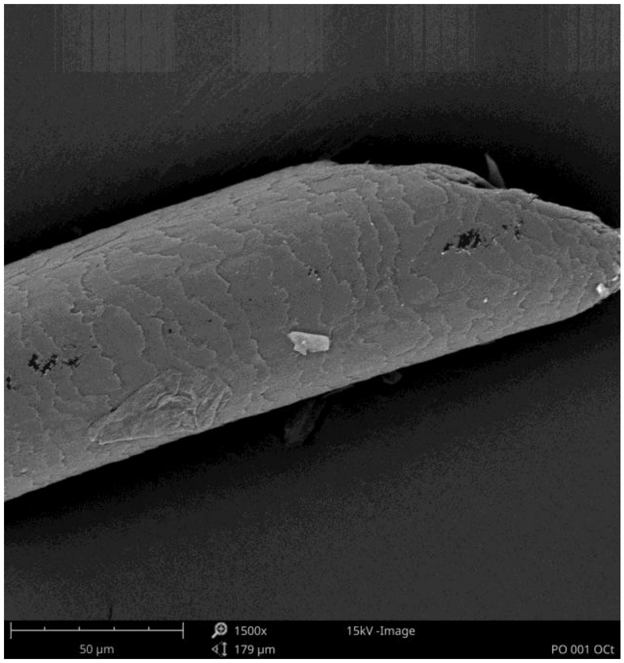
Regular mosaic, smooth, near

b. Proximal



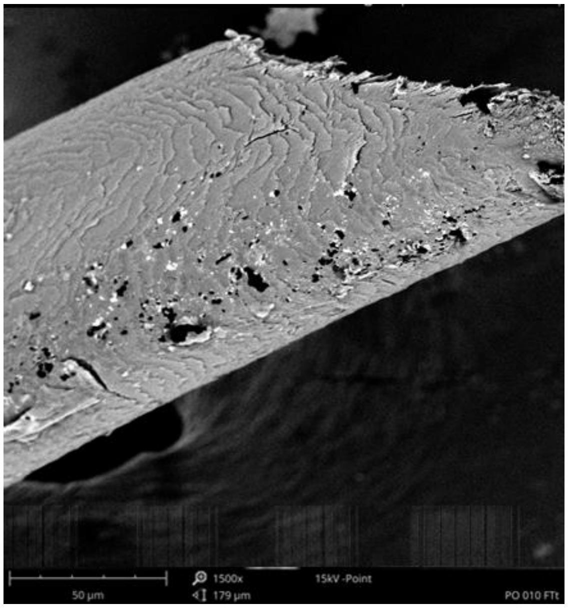
Regular waved, smooth, close

c. Distal



Irregular waved, rippled, near

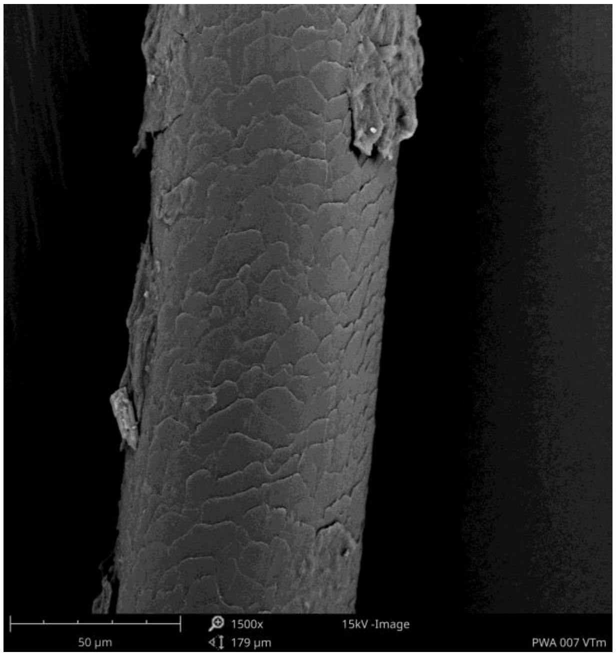
d. Distal



Irregular waved, rippled, close

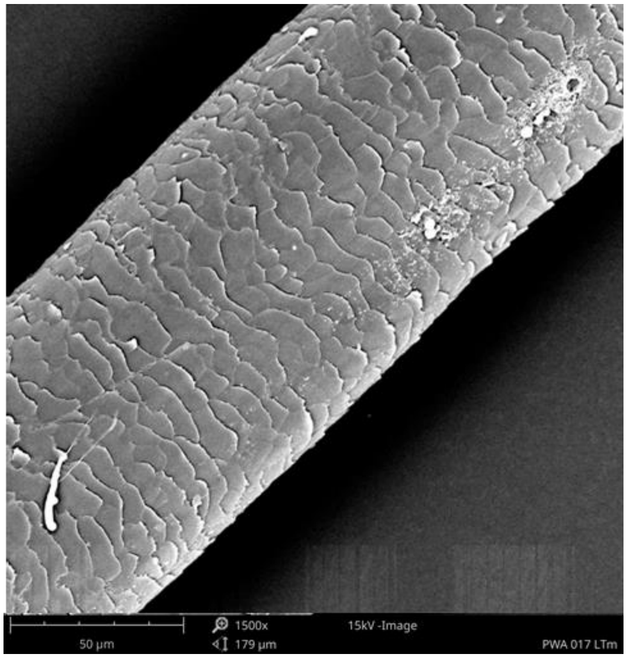
Figure 16 (a-d): Scanning electron micrographs of representative samples of proximal (a & b) and distal (c & d) hairs illustrating scale patterns. Samples were from male PWO. Magnification is indicated by the scale bar generated by the SEM.

a. Proximal



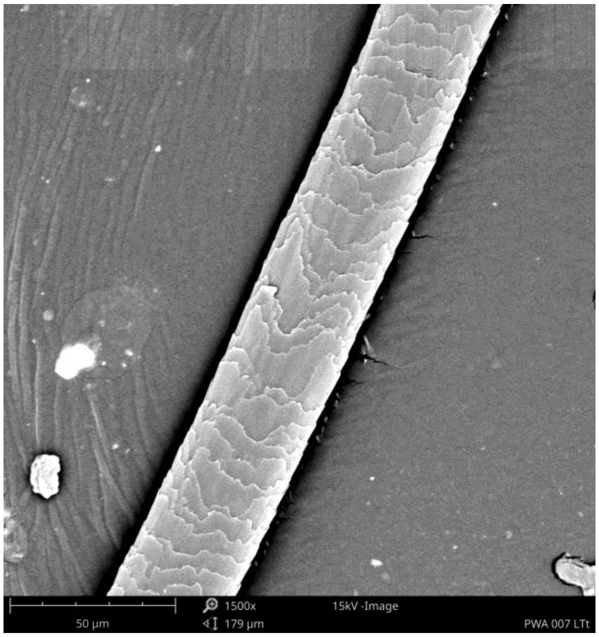
Regular mosaic, smooth, near

b. Proximal



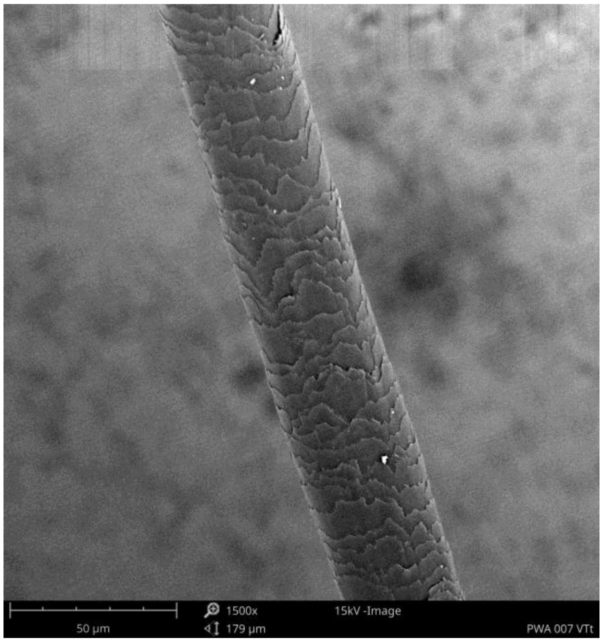
Regular wave, smooth, near

c. Distal



Irregular waved, crenate, distant

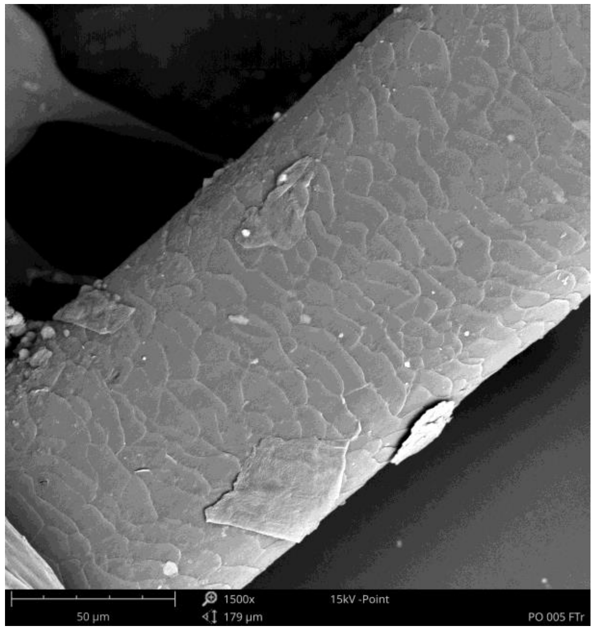
d. Proximal



Irregular waved, rippled, near

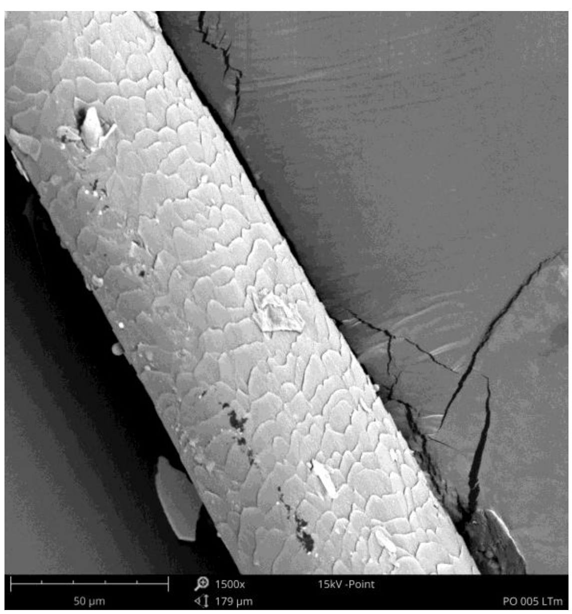
Figure 17(a-d): Scanning electron micrographs of representative samples of proximal (a & b) and distal (c & d) hairs illustrating scale patterns. Samples were from female PWA. Magnification is indicated by the scale bar generated by the SEM.

a. Proximal



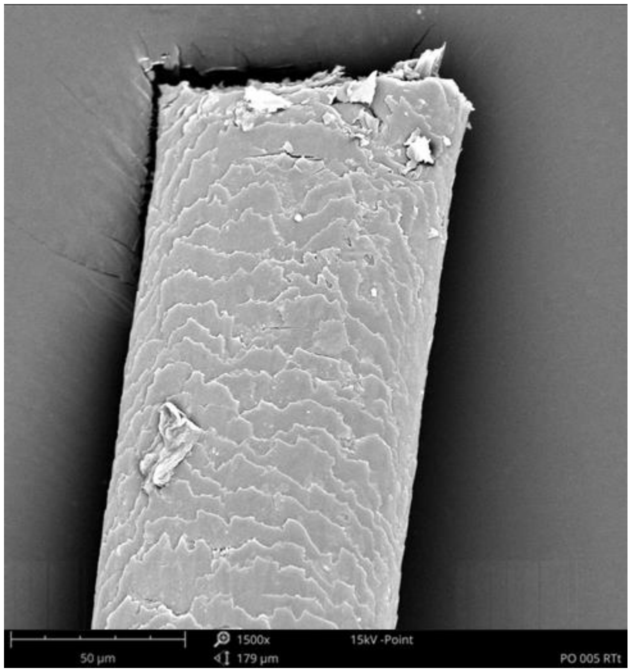
Regular waved, smooth, near

b. Proximal



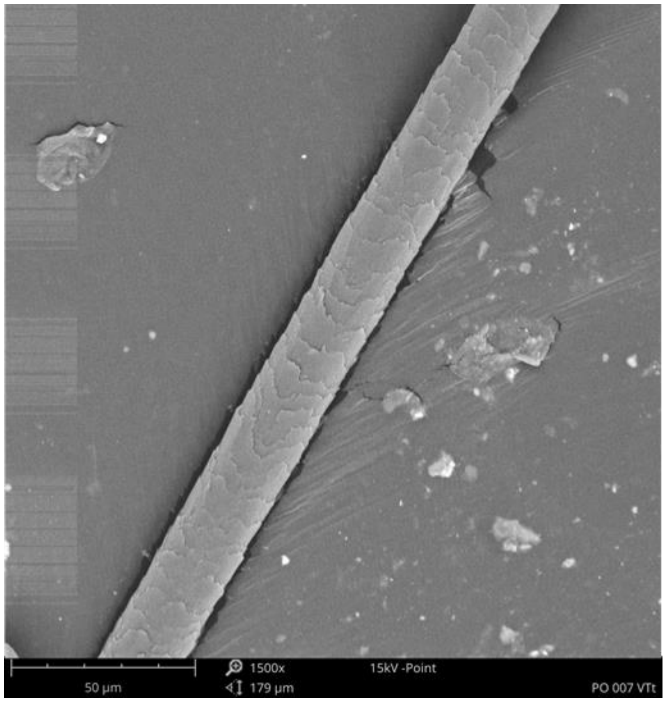
Regular mosaic, smooth, near

c. Distal



Irregular waved, rippled, near

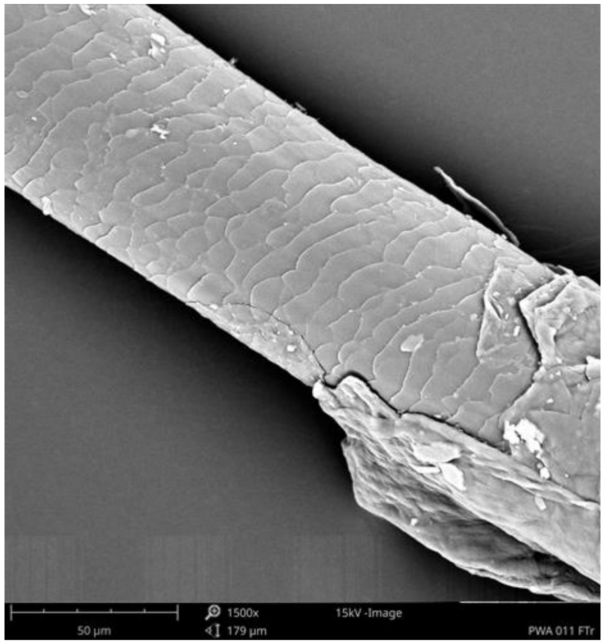
d. Distal



Irregular waved, rippled, near

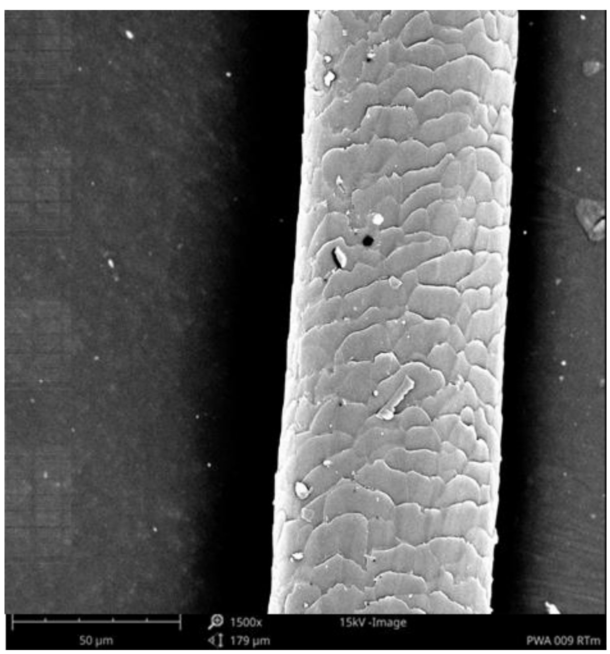
Figure 18 (a-d): Scanning electron micrographs of representative samples of proximal (a & b) and distal (c & d) hairs illustrating scale patterns. Samples were from female PWO. Magnification is indicated by the scale bar generated by the SEM.

a. Proximal



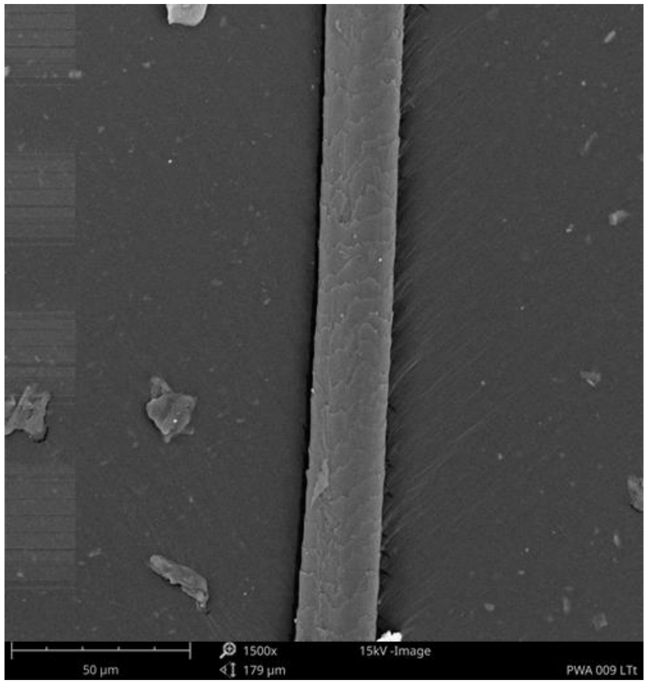
Regular waved, smooth, near

b. Proximal



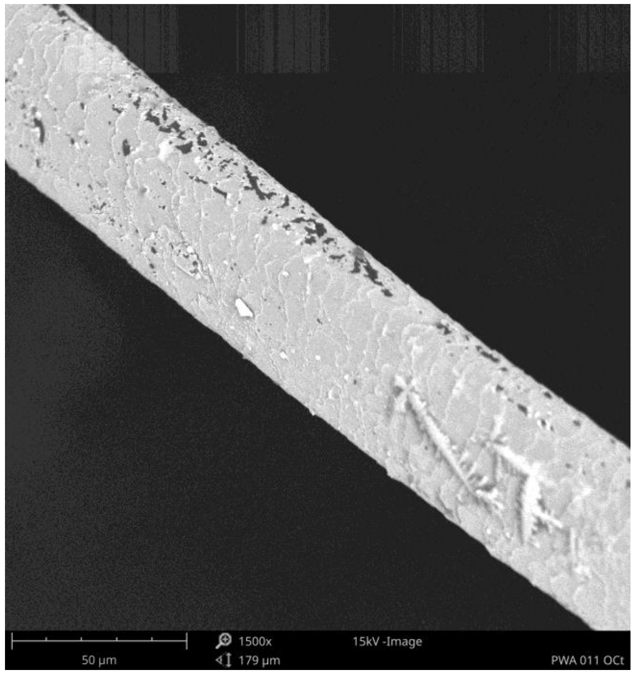
Regular mosaic, smooth, near

c. Distal



Irregular waved, rippled, near

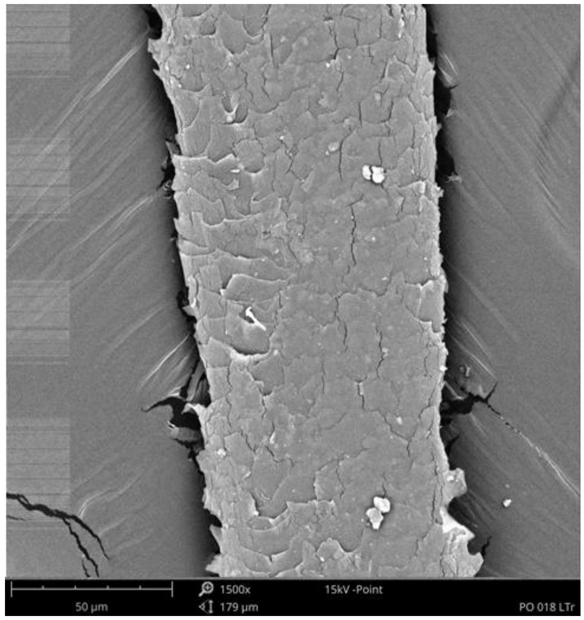
d. Distal



Irregular waved, rippled, close

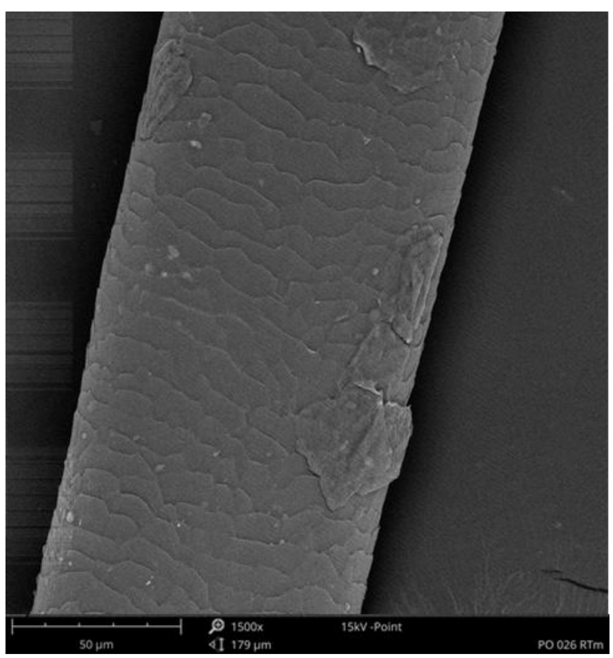
Figure 19 (a-d): Scanning electron micrographs of representative samples of proximal (a & b) and distal (c & d) hairs illustrating scale patterns. Samples were from female PWA. Magnification is indicated by the scale bar generated by the SEM.

a. Proximal



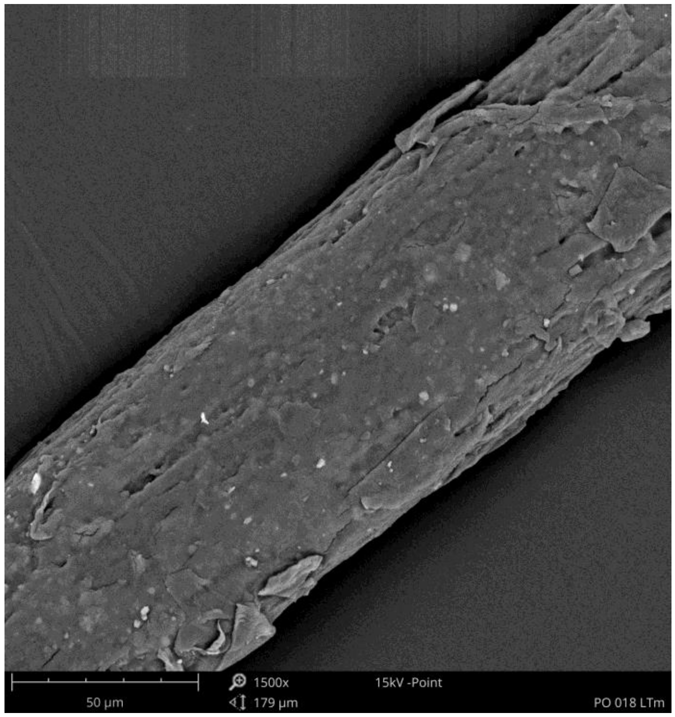
Irregular waved, crenate, near

b. Proximal



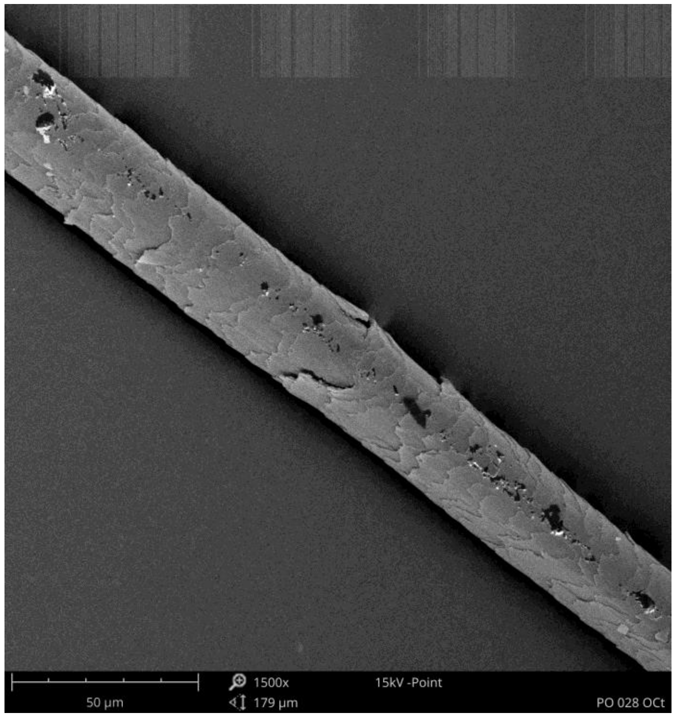
Regular waved, smooth, near

c. Distal



No scales

d. Distal



Irregular waved, rippled, near

Figure 20 (a-d): Scanning electron micrographs of representative samples of proximal (a & b) and distal (c & d) hairs illustrating scale patterns. Samples were from female PWO. Magnification is indicated by the scale bar generated by the SEM.

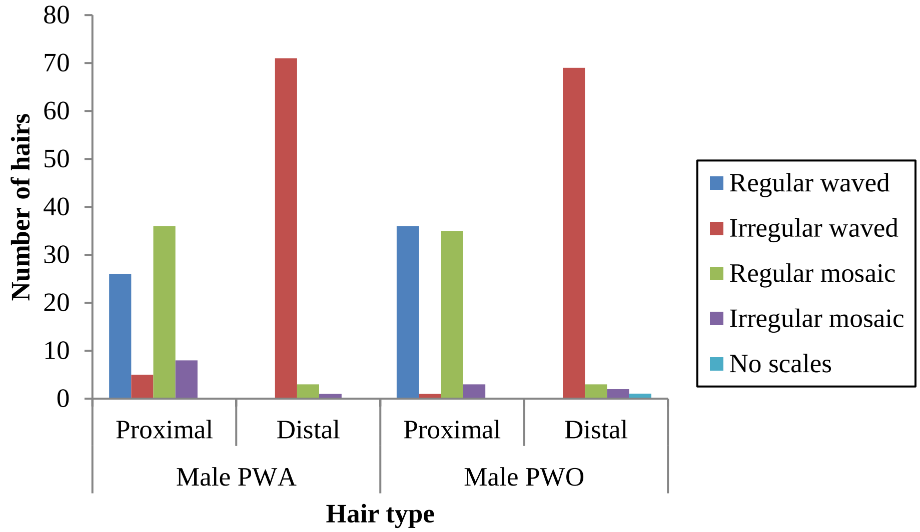


Figure 21: A bar chart showing the occurrence of scale patterns among the proximal and distal shafts of male PWO and PWA.

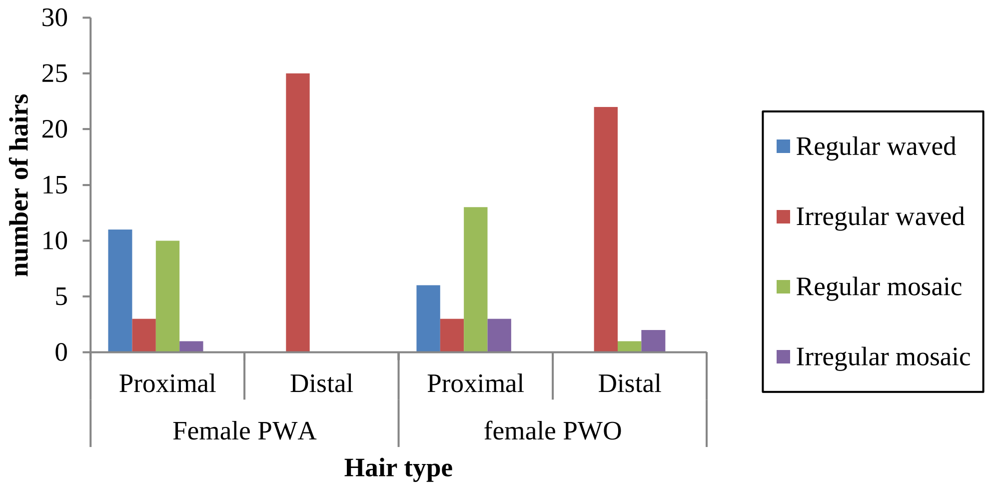


Figure 22: A bar chart showing the occurrence of scale patterns among the proximal and distal shafts of female PWO and PWA with natural styled hair.

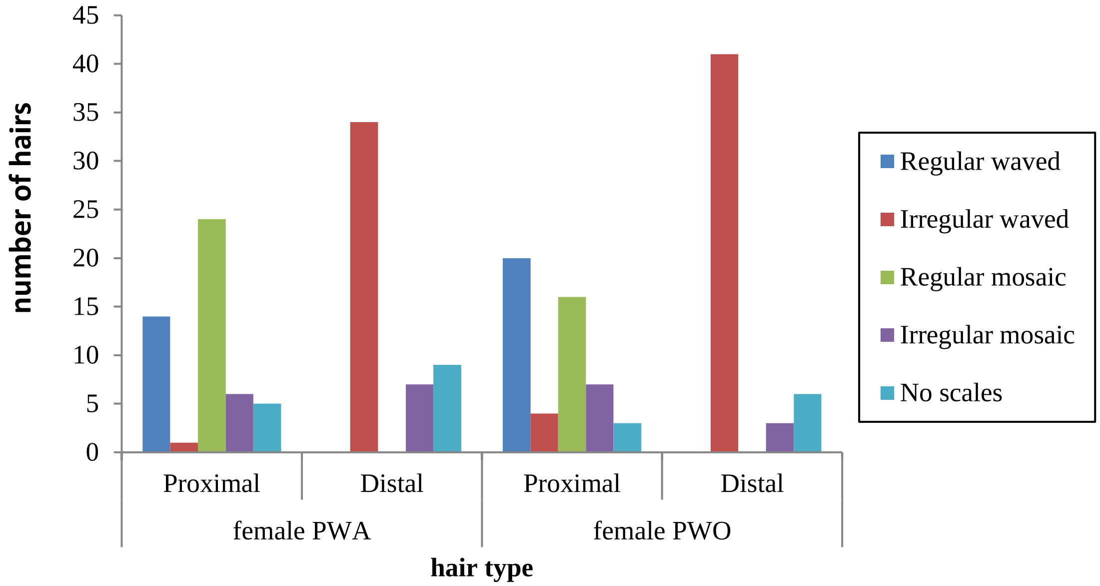


Figure 23: A bar chart showing the occurrence of scale patterns among the proximal and distal shafts of female PWO and PWA with permed hair

4.4.4 Nature of scale margins

The scale margins were categorized into smooth, rippled and crenate (Figures 15-20). The proximal and distal portions of hair shaft were considered for this description. The smooth scale margins occurred the most among the proximal shafts of Male PWA (62/75, or 82.67%), Male PWO (71/75, or 94.67%), female PWA with natural styled hair (21/25, or 84%), female PWO with natural styled hair (18/25, or 72%), female PWA with permed hair (38/50, or 84.44%) and female PWO with permed hair (36/50, or 76.6%). The rippled scale margins had highest occurrence in the distal hair shafts of male PWA (72/75, or 96%), male PWO (70/75, or 93.33%), female PWA with natural styled (24/25, or 96%), female PWO with natural styled hair (24/25, or 96%), female PWA with permed hair (37/50, or 90.24%) and female PWO with permed hair (43/50, or 97.92%). The crenate scale margins in the proximal portions of the hair shaft showed the following prevalence; male PWA (9/75, or 12%), male PWO (3/75, or 4%), female PWA with natural styled hair (3/25, or

12%), female PWO with natural styled hair (6/25, or 24%), female PWA with permed hair (7/50, or 15.56%) and female PWO with permed hair (8/50, or 17.02%). The crenate scale margins in the distal shaft of the hair showed the occurrence as follows: male PWA (0/75, or0%), male PWO (1/75, or 1.33%), female PWA with natural styled hair (1/25, or 4%), female PWO with natural styled hair (0/25, or 0%), female PWA with permed hair (4/50, or 9.76%) and female PWO with permed hair (1/50 or 2.27 %). Chi square test showed no significant variation between the nature of scale margins of PWA and PWO In proximal shafts of hair, Chi square test showed that there was no significant variation between the scale patterns of Male PWA and PWO (p=0.0669), female PWA and PWO with natural styled hair (p=0.5404) and female PWA and PWO with permed hair (p=0.7407). In distal shafts of hair, Chi square test showed that there was no significant variation between the scale patterns of Male PWA and PWO (p=0.9730), female PWA and PWO with natural styled hair and female PWA and PWO with permed hair (p=0.1429).

The occurrence of the scale margins found in the proximal and distal portions of the hair shaft are presented in Figures 24, 25, and 26.

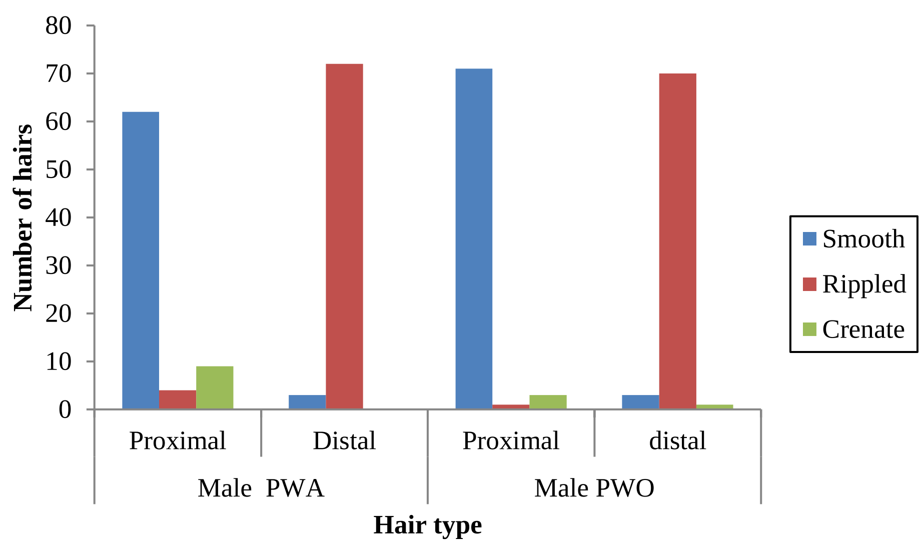


Figure 24: A bar chart showing the number of hairs in the proximal and distal parts of the hair shaft with the various scale margins in male PWA and PWO.

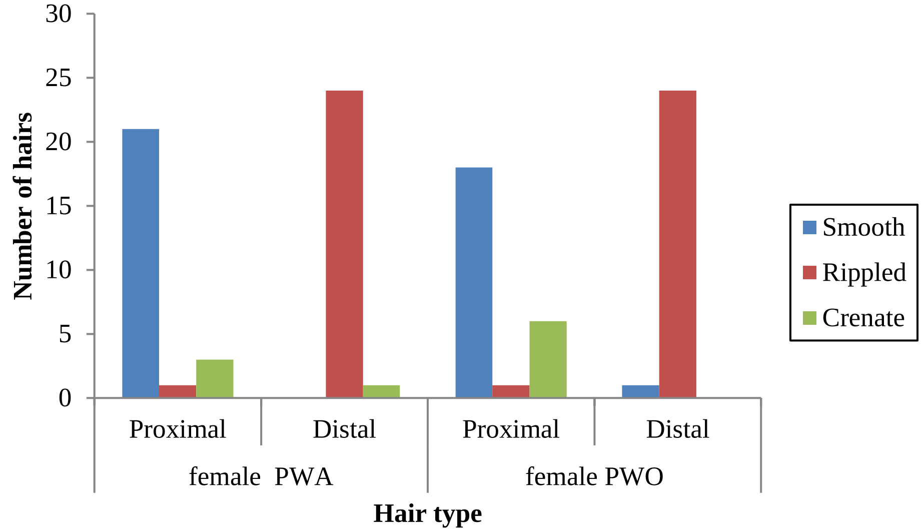


Figure 25: A bar chart showing the number of hairs in the proximal and distal parts of the hair shaft with the various scale margins in female PWA and PWO with natural styled hair.

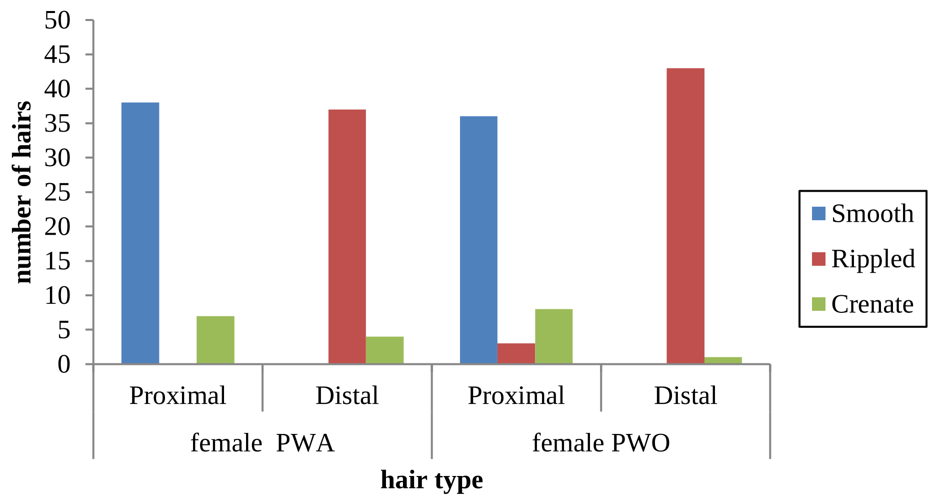


Figure 26: A bar chart showing the number of hairs in the proximal and distal parts of the hair shaft with the various scale margins in female PWA and PWO with permed hair.

4.4.5 Distance between the scale margins

Close, near, and distant were characteristics used to describe the intervals between the scale margins of the hair shaft, with respect to decreasing proximity between them. For the proximal hair shaft, of male PWA, the near type (54/75, or 72%) was highest in occurrence followed by the distant type (17/75, or 22.67%) and the least being the close type (4/75, or 5.33%). In the proximal hair shaft of male PWO, the near type (71/75, or 94.67%) was highest in prevalence, followed by the close type (3/75, or 4%) and then the distant type (1/75, or 1.33%). For the distal hair shaft of male PWA, the near type (34/75, or 45.33%) was highest, followed by the close type (23/75, or 30.67%) and then the distant type (18/75, or 24%). In the distal hair shaft of male PWO, the near type (41/75, or 54.67%) occurred the most, followed by the close type (20/75, or 26.67%), and then the distant type (9/75, or 12%).

For female PWA with natural styled hair, in the proximal hair shaft had near type (22/25, or 88%) with highest occurrence, followed by the distant type (2/25, or 8%) and the close type (1/25, or 4%). Among the proximal hair shaft of female PWO with natural styled hair, the near type (20/25, or 80%) occurred the most, followed by the distant type (5/25, 20%). In the distal part of the hair shaft of female PWA with natural styled hair, the near type (11/25, or 44%) was highest in prevalence, followed by the close type (8/25, or 32%) and then the distant type (6/25, or 24%). Among the distal hair shaft of female PWO with natural styled hair, there was preponderance of near type (18/25, or 72%), followed by distant (6/25, or 24%) and then close (1/25, or 4%).

For female PWA with permed hair, the proximal part of the shaft had the near type of distance between scale margins dominating (41/50, or 82%), followed by the distant type (3/50, or 6.67%), and the close type (1/50, or 2%) being the least. In the proximal hair shaft of female PWO with permed hair, the near type (41/50, or 82%) was highest in prevalence, followed by distant type (5/50, or 10%) and the least being the close type (1/50,or 2%). In the distal hair shaft of female PWA with permed hair, the near type (23/50, or 56%) was highest in preponderance, followed by distant type (12/50, or 24%) and the least being the close type (6/50, 12%). Among the distal hair shaft of female PWO with permed hair, the near type (25/50, or 50%) was highest in occurrence, followed by distant type (15/50, or 30%), and the least being the close type (4/50, or 8%). The distance between scale margins did not show any much variation between PWA and PWO except for the proximal shaft of the hair of male PWA and PWO. In proximal shafts of hair, Chi square test showed that there was a significant variation between the scale patterns of Male PWA and PWO (p=0.0002) but no significant variation between female PWA and PWO with natural styled hair (p=0.2433) and female PWA and PWO with permed hair (p=0.8123). In distal shafts of hair, Chi square test showed that there was no significant variation between the scale patterns of Male PWA and PWO (p=0.1577), female PWA and PWO with natural styled hair(p=0.0624) and female PWA and PWO with permed hair (p=0.7066).

A graphical presentation of prevalence of the three types of distance between scale margins among proximal and distal parts of hair shafts is shown in Figures 27-29. Figure 27, 28 and 29 show the number of hairs in the proximal and portions of the hair shaft with scale separation types in PWA and PWO.

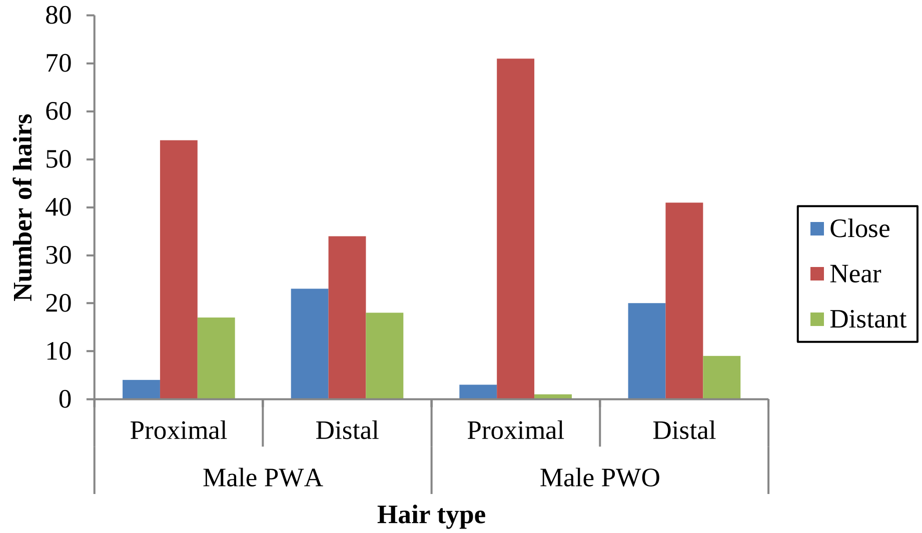


Figure 27: A bar chart showing the number of hairs in the proximal and distal parts of the hair shaft with various types of distance between scale margins in male PWO and PWA.

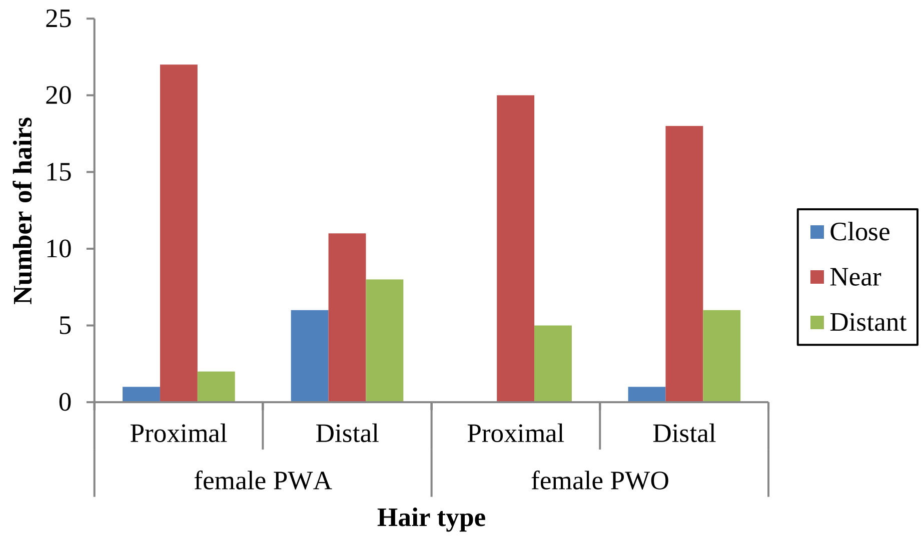


Figure 28: A bar chart showing the occurrence of various types of distance between scale margins in the proximal and distal hair shaft in female PWO and PWA with natural styled hair.

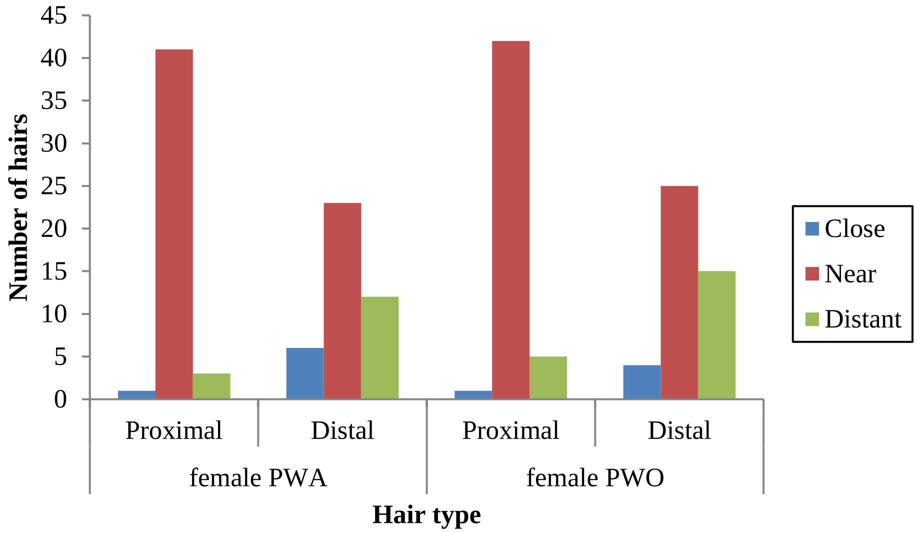


Figure 29: A bar chart showing the prevalence of various types of distance between scale margins among proximal and distal hair shaft in female PWO and PWA with permed hair.

4.5 Morphology of the root and tip of hair

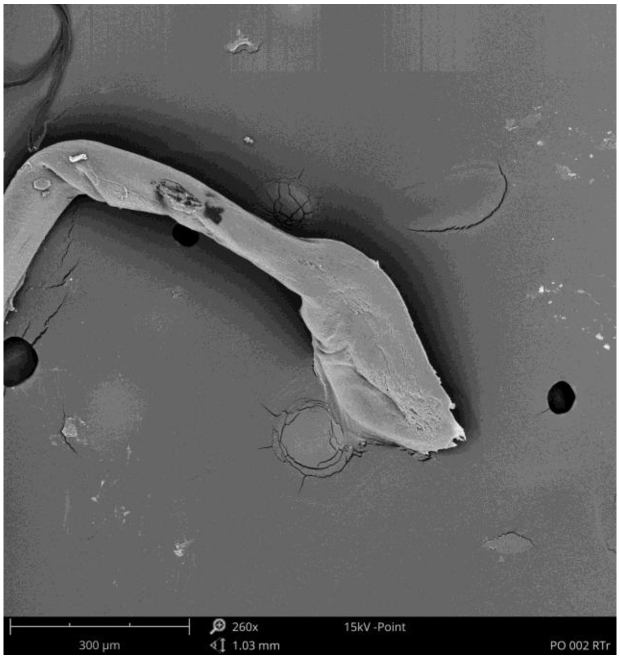
The roots of the hairs were classified as anagen, catagen and telogen roots, according to literature descriptions. Similarly, the tips of the hairs were classified as fibrillated, finely pointed, razor cut, or blunt. In both groups, hair roots were mostly anagen roots with a followed by catagen and telogen roots which are about just equal. Representative samples of the morphology of the root of hairs in both PWA and PWO are shown in Figure 30. A greater number of hairs of male participants showed razor cut or blunt tips whereas hairs from female participants more commonly showed finely pointed, blunt pointed or blunt tips in both PWA and PWO. Representative samples of hair tips found in this study are illustrated in Figure 31. The occurrence of types of roots and tips among the study population are shown in the Table 9 and 10.

Table 9: The occurrence of types of roots in study population

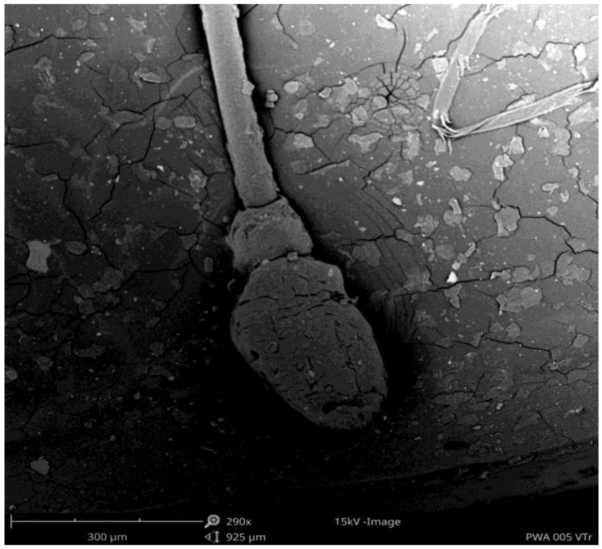
	Root type		
Hair style	Anagen root	Catagen root	Telogen root
PWA Male hairs (n=62)	42 (68%)	9 (15%)	11(18%)
PWA Female with Natural styled hair (n=17)	13(76%)	2 (12%)	2 (12%)
PWA Female with permed hair (n=32)	21(66%)	4 (12.5%)	7(22%)
PWO Male hairs (n=68)	45(66%)	11(16%)	12(18%)
PWO Female with Natural styled hair (n=17)	10 (63%)	3(19%)	3 (19%)
PWO Female with permed hair (n=37)	22(60%)	6 (16%)	9(24%)

Table 10: The occurrence of types of roots in study population

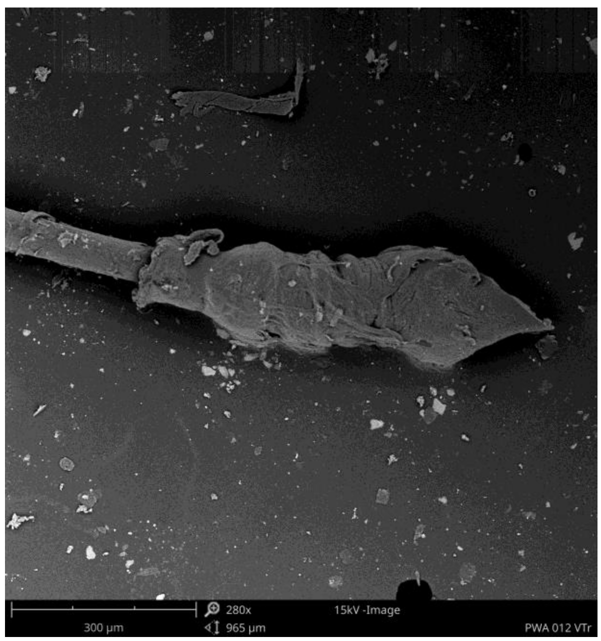
	Root tips			
Hair types	Razor cut	Blunt	Pointed	Fibrillated
PWA Male (n=75)	34 (45%)	39 (52%)	2 (3%)	0 (0%)
PWA female with natural styled hair (n=25)	0 (0%)	17 (68%)	7 (28%)	1 (4%)
PWA with permed hair (n=50)	0 (0%)	36 (72%)	2(4%)	12 (24%)
PWO Male (n=75)	37 (49%)	35 (47%)	3 (4%)	0 (0%)
PWO female with natural styled hair (n=25)	0 (0%)	9 (36%)	16 (64%)	0 (0%)
PWO with permed hair (n=50)	0 (0%)	34 (68%)	5 (10%)	11(22%)



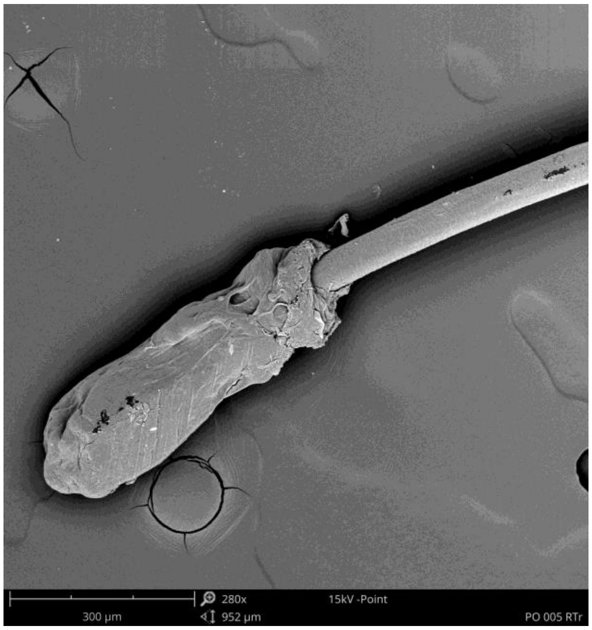
a. Anagen root



b. Telogen root

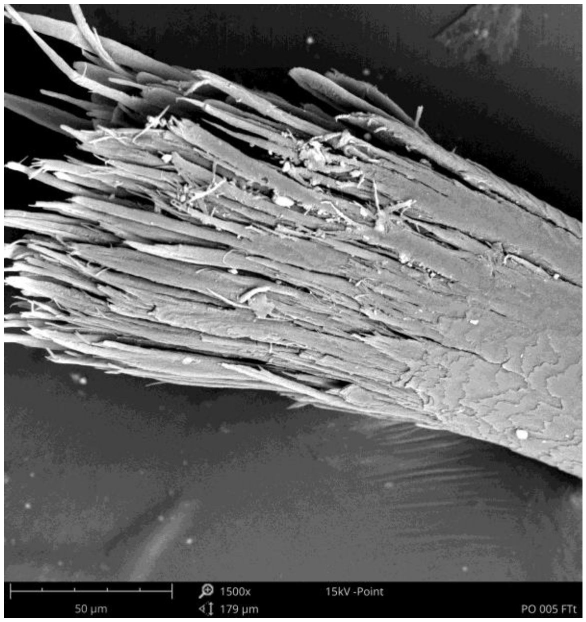


c. Catagen root

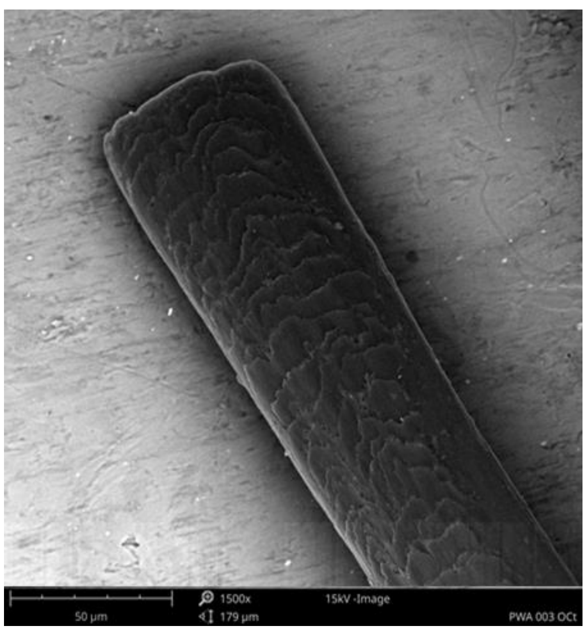


d. Telogen

Figure 30(a-d): Scanning electron micrographs showing representative samples of morphological types of hair roots found in the study population.

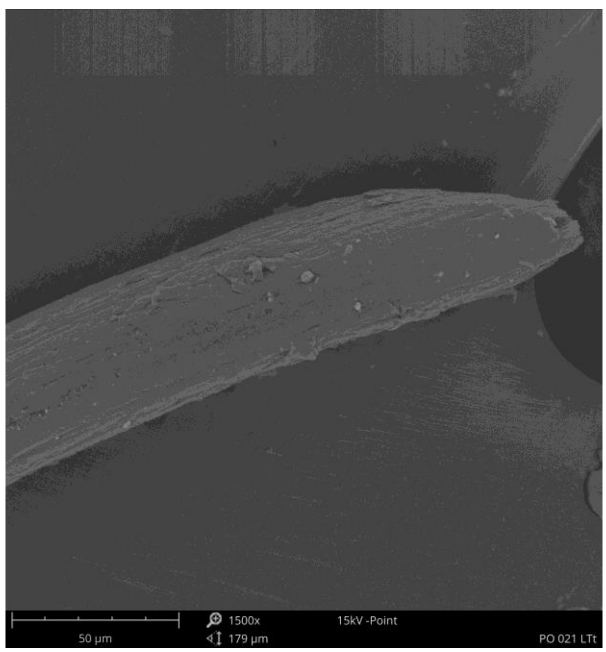


a. Fibrillated tip



b. Blunt tip

c. Finely pointed tip



d. Razor cut tip

e. Blunt pointed tip

Figure 31(a-e): Scanning electron micrographs showing representative samples of morphological types of hair tips found in the study population

CHAPTER FIVE

5.0 DISCUSSION

5.1 SEM-EDS Analysis

By far the most clear-cut difference found hairs of PWA and PWO is their boron content as recorded by the Scanning electron microscope's Energy dispersive spectra (EDS). There was between 5 to 6-fold higher Boron content of the hair shafts of PWA compared to hairs of PWO. The higher boron of hairs of PWA probably arises from sunscreen and blemish creams PWAs use to protect their skins from solar UV radiation which is exceptionally pernicious to their cutaneous hypomelanism. Sunscreen and blemish balm creams usually have inorganic and organic compounds to serve as sunlight filters (Manaia *et al*., 2013; Morabito *et al*., 2011). Studies have shown that in addition to titanium oxide and zinc oxide, boron nitride has been added to ingredients of sunscreens and other blemish creams which are safe in cosmetics in the practices of use and concentration (Türkez *et al*., 2019; Fiume *et al*., 2015). Boron nitride is used to strengthen the light protection factor of cosmetic or dermatological compositions to protect from light which contains conventional UV filter substance (Gers-Barlag and Muller, 2000). The Boron content being higher in PWA than in PWO may be due to the use of sunscreens or blemish creams which may contain boron nitride. In any case, it is attractive to propose inclusion of EDS analysis when it comes to identification of hair. The hair EDS components adds another layer of distinction between different samples by means of their elemental analysis (Das *et al*, 2018). According to Dahiya and Yadav (2013), EDS analysis gives significant information of hair which can be used as a species and geographical identification tool.

The present study found that the first three elements in higher weight percentage in hairs from PWA and PWO were Carbon, Oxygen and Nitrogen in decreasing order. A similar pattern was observed by Mujeeb and Zafar (2017) in which the carbon content ranged between 37.5% and 48.31%, oxygen content ranged between 22.84 and 34% and Nitrogen content ranged between 14.77 and 20.8%. Carbon, oxygen, nitrogen, and Sulphur remain an integral part of the hair fibre structure (Robbins, 2012). The high carbon content in the hair shaft increases with age and this may be due to the loss of inorganic material from the hair (Mujeeb and Zafar, 2017). The loss is then followed by a subsequent increase of organic material. In both PWA and PWO, Sulphur was the fourth highest element in hair, which agrees with report by Mujeeb and Zafar (2017). The occupation of individuals and exposure of persons to harmful substances decreases the level of Sulphur by lessening the Sulphur proteins in the hairs. The decrease in the levels of Sulphur is due to the damage of bonds by acidic and alkaline groups which may lead to structural abnormalities in the hairs. Calcium (0.12 – 0.43%) was also found in hair shaft using EDS analysis which falls in the range of Calcium content found in the hairs studied by Mujeeb and Zafar (2017). Calcium is known to be an important element in biological systems and plays a role in structural material. It can also be found in other tissues such as bone, shells of molluscs, horns, hoofs etc. Magnesium was found to be less in quantity for both groups compared with data from Mugeez and Zafar (2017) whose study of different aged males had sodium to be the element in lesser quantity. The possible explanation may be due to ethnic differences. Also it is important to know that the amount of trace elements in hairs are subjective and may vary from person to person. Robbins (2012) proffered that the presence of sodium, potassium and magnesium in hair may be because of the use of soaps or shampoos which contain these elements as ingredients.

5.2 Quantitative characteristics

5.2.1 Hair shaft diameter

This study found no significant variation between the hair shaft diameters of PWA and PWO except the OC region of the scalp for male PWA and PWO. This means that the hairs of PWA and PWO have similar mean hair shaft diameters.

The mean shaft diameter of the both PWA and PWO were greater in males than in females and these findings are similar to Gaur *et al*. (2007) whose study on variation in scalp hair among Brahmins and Banias showed that mean hair shaft diameter was greater in males than females. The findings of this study were contrary to Jasuja and Minakshi (2002) whose studied on Rajput males and females and found that the hair shaft diameters of females were greater than males. The difference between the hair shaft diameter of both male and female PWA and PWO was however not big. It is believed that both male and females share similar genetic factors when it comes to hair proliferation.

Findings from Essel *et al*. (2019) showed that chemically styled hair had greater shaft diameter compared to natural styled and natural unstyled hair of Ghanaian females which is similar to findings of this study considering female PWA and PWO. Miranda-Vilela *et al*. (2013) suggested that chemical relaxers that are used to relax the hair, damages the hair and removes the monomolecular layers of fatty acids bound covalently to the hair cuticle. The removal of these fatty acids makes the hair susceptible to static electricity and curling induced by humidity. Relaxed hair after being treated with relaxers and chemicals allows water to penetrate it making the hair shaft swell. This may account for the greater shaft diameter in permed hair than in natural styled hair of both PWA and PWO.

For female PWA and PWO with permed hair, the largest shaft diameter was found in the vertex. Similar findings were reported in earlier studies (Essel *et* al., 2019; Mulinari-Brenner *et al*., 2006). According to Essel *et al*. (2019) hairs from the vertex region from all the styling groups (natural unstyled, natural styled and relaxed hair) had the highest shaft diameter in the vertex of the scalp. Mulinari-Brenner *et al*. (2006) in their study on Brazilians recorded greatest parameters in the vertex of the scalp. Female PWA with natural styled hair had the greatest shaft diameter in the frontal region of the scalp which is similar to the findings of Leerunnyakul and Suchonwanit (2020) who evaluated the hair density and hair diameter in adult Thai population using quantitative trischoscopic analysis. In their study, the authors found that the largest hair diameter was found in the frontal region of the scalp for males and females. In male PWA, the greatest mean hair shaft dimeter was found in right temporal region and least in the occipital region. In male PWO, the greatest mean shaft diameter was found in the left temporal region and least in the occipital region. In female PWO with natural styled hair, the greatest hair shaft diameter was found in right temporal region and least in the left temporal region. In the early stage of hair follicular morphogenesis, the Wnt pathway transduce from the mesenchymal cells to form a placode which leads to the growth of the hair germ (Schneider *et al*., 2009). The variations in the hair follicles in the scalp regions may be due to the number of mesenchymal cells transcending the signals. Baque *et al*. (2012) showed in their study that hair thickness is dependent on the hair growth rate. As hair size is dependent on the size of the hair follicle which depends also on the size of the dermal papilla (Chi *et al*. 2013), hair follicles that grow faster are expected to be larger to produce thicker hair shaft.

5.2.2 Mean scale count (MSC) and Interval between scale margin (ISM)

The MSC and ISM were higher in PWA compared to PWO in both the proximal and distal portions of the hairs from the various scalp regions. The proximal shaft showed higher ISM than the distal shaft in both groups. The results from this study showed that hairs with larger MSC had bigger ISM in PWA. This suggests a positive correlation between the MSC and ISM for both the proximal and distal portions of the hair shafts of PWA. These findings are similar to the findings of Essel *et al*. (2019) and contrary to the findings of Aboagye *et al*. (2014). In PWO, hairs with smaller MSC had larger ISM for both the proximal and distal portion of the hair shaft which agrees to the findings of Aboagye *et al*. (2014).

Female PWA and PWO with permed hair showed lower MSC compared to female PWA and PWO with natural styled hair. The lower MSC in permed hair may be attributed to the loss of scales resulting from use of hair relaxers for a period of time compared to natural hair which is hardly exposed to hair relaxers. Permed hairs after being exposed to chemicals such as relaxers undergo some changes which includes the removal of 18-methyl eicosanoic acid (18-MEA). The 18-MEA plays a role in scale adhesion. The degradation of 18-MEA may cause faster cuticle disintegration and cuticle loss eventually.

5.3 Qualitative assessment of scales

5.3.1 Scale patterns

For both groups, the scale pattern in the proximal portion of the hair shaft showed a more regular mosaic pattern than regular waved pattern. In the distal portion of the hair shaft of both groups, the scale pattern was predominantly irregular waved. The proximal portion of the hair shaft of both male and female PWA and PWO showed higher occurrence of regular scale pattern than the distal portion of the hair shaft. This finding is concurrent with Essel *et al*. (2019) on microscopic characteristics of scalp hair subjected to cultural styling methods in Ghanaian African females. According to the authors, the proximal portion of the hair shaft showed regular scale patterns than the distal portion. Khenniche *et al*. (2003) reported that when scalp hair emerges, the ends of the scales are regular and smooth. When the hair length increases away from the scalp, mechanical contact of the hair to other surfaces and hair strands modify the nature from a regular to an irregular pattern. This current finding is also in line with Kitpipit and Thanakiatkrai (2013) whose study was on Tigers. Their study found that the scale pattern in the proximal portion of the hair shaft showed a regular waved pattern compared to the distal portion which showed none.

5.3.2 Scale margins

The scale margins in the proximal portion of the hair shafts of both male and female PWA and PWO showed a preponderance of smooth scale margins and the distal portion of the hair shaft showed rippled scale margins. These findings are similar to Essel *et al*. (2019) who reported smooth scale margins to be significantly higher prevalence in the proximal portions of the hair shaft than in the distal portion of the hair shaft in natural unstyled, natural styled and relaxed hairstyle groups in Ghanaian females. Also, Essel *et al*. (2019) showed rippled scale margins to have significantly higher occurrence in the distal portion of the hair shaft than in the proximal portion of the hair shaft in the hairstyle groups studied. The reason for the smooth nature of the scale margins in the proximal portion of the hair shaft than the distal portion may be due to less exposure to chemicals and mechanical wear. The margin of the scales shows the state of the cuticular scales and therefore the smoother the scale margins, the better the state of the scales. The distal part showed rippled scale margins due to exposure to chemical and mechanical wear. The findings of this present study are similar to the results of Kalmoni *et al*. (2019) which also showed smoother than crenate scale margins in both Adolescent male and female hairs. Even though comparisons with the latter study is limited by failure to state which region of the scalp the hairs were plucked from as well as which portion of the hair shaft was taken into consideration. The findings of this current study are also similar to Sarma *et al*. (2014) and Kitpipit and Thanakiatkrai (2013) who studied the morphology and variations of the hairs of tigers.

5.3.3 Distance between scales

Generally, the distance between the scales showed higher proportions of the near type followed by the distant and close types in both PWA and PWO. In both male PWA and PWO, the highest proportion of scale separation in the proximal portion of the hair shaft was the near type followed by the distant type and close type, respectively. In the distal shaft of male PWA and PWO the near type was the highest in proportion followed by close type and distant type, respectively. In female PWA and PWO who had natural styled hair and permed hair, the highest proportion of scale separation in both the proximal and distal portions of the shafts to be the near type followed by distant and close types. These findings were similar to Essel *et al*. (2019) whose study showed the highest proportion of scale separation being the near type, followed by the distant type and the close type for relaxed and natural styled hairs.

In general, most of the hair in the proximal and distal shaft showed a proportion of scale separation to be the near type in both PWA and PWO. According to Kalmoni *et al*. (2019) most Adolescent male and female hairs had the near type or close type as the interval between the margins. In their study, it was observed that few hair shafts showed the distant type of scale margin. Studies from Braque *et al*. (2012) showed that the inter scale distance is shorter in thicker hair shafts. In this study thinner hair shafts showed wider distance between the margins while thicker hair strands showed shorter distances between the margins in both PWA and PWO. Hairs had distant scale separation types because of the larger sizes of the scales. The near type of scale separation found in higher proportion in the proximal portion of the hair shaft of both groups. This is because when the hair emerges from the scalp, it is expected to maintain the morphological characteristics of the scalp since the proximal portion of the hair shaft is closer to the scalp. The distal portion of the hair shaft showed a higher proportion of close type of scale separation in both male PWA and PWO. The close nature of the scale to each other may be because of wear and tear. The possible explanation is that wear and tear may be attributed to the intensity of trauma to the hair by grooming such as trimming which make the scales become closer to each other preceding their loss completely.

5.4 Type of roots and nature of the tip

In this study, the anagen roots were commoner compared with catagen and telogen roots for both groups. This may be due to the hair growth pattern; the region of the body being considered as well as the method of plucking the hair sample for the study. Every hair follicle is independent and goes through the hair growth cycle at different times. According to Stene (2004), a greater percentage of scalp hairs are in the anagen phase of the hair growth cycle followed by the catagen and the telogen phases. Hairs were plucked from different regions at random using a pair of cosmetologist tweezers in this study and the probability of picking hairs in anagen growth phase may be higher.

The tips of the natural unstyled hair had blunt razor cut tip morphology. Most males in Ghana adopt regular haircut as socially acceptable grooming method. For this reason, the nature of their hair tip is blunt razor cut tips which is expected. Natural styled hair for both groups showed either finely pointed tips or blunt tips. The blunt nature of the tips may be due to the breakage at the tips. The finely pointed nature of the hair tips may arise from normal patterned loss of the cuticle related to grooming. The relaxed hairs for both groups showed fibrillation of the tips as well as blunt cut ends. The use of hair relaxers and chemicals weaken the tips of the hair, removes pigment granules and can also disturb the scales on the cuticle (Robbins, 2012). The tips of relaxed hair are trimmed occasionally to avoid fibrillation (Essel *et al*., 2019).

5.5 Conclusion

The scale patterns of the hairs of Persons with and without albinism showed similar scale patterns in both the proximal and distal ends of the hair shaft. The most distinctive feature of scalp hairs of PWA is a 5-6 fold higher boron content compared to hairs of PWO using EDS analysis. Albinism is apparently not accompanied by significant morphological or topographical scalp hair differences compared with normo-melanistic individuals.

5.6 Limitations

- Measuring the diameter of the hair shaft as well as scale counts were difficult. Software that can generate these variables can be used to improve the methods.
- Determination of the scales patterns were observer-dependent making experience and human vision a limiting factor. Mechanical or automated methods of determining scale patterns can be used.

5.7 Recommendations

- Further studies should be carried out on scalp hairs of Albinos compared with grey hair and dyed hair.

- Further studies should be carried out to ascertain the basis for higher boron content of albino scalp hairs, compare EDS of hairs from newborn albino babies with age-matched non albinos. This can be done to find out whether the high Boron is from birth or as one ages, certain exposures to cosmetics cause the increase in the stated element.

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APPENDIX ONE

INFORMATION SHEET

Participant Number: ………….……………….

Title of Research Project: Scanning Electron Microscopic (SEM) study of scalp hairs of persons with and without Albinism

Principal investigator: Abigail Owusua Yeboah

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CONSENT TO PARTICIPATE IN A RESEARCH PROJECT

Before you agree to participate in this research study, it is important that you read and understand the following study. This statement describes the aim, procedure, risks, discomforts and precautions as well as your right to withdraw from the study at any time.

You are being invited to participate in a research project title: '**SCANNING ELECTRON MICROSCOPY (SEM) STUDY OF SCALP HAIRS OF PERSONS WITH AND WITHOUT ALBINISM**.

The aim of this study is to determine the morphological profile of Ghanaian Albinos

Explanation of procedures

The purpose of the research is to determine the morphology of albino hairs using the Scanning Electron Microscope (SEM). This is to allow hairs to be plucked using a pair of cosmetologist tweezers. A hair strand will be plucked randomly from the four regions of the scalp and the eyebrows. The regions of the scalp are namely; the frontal, left temporal, right temporal and the occipital regions. The hairs will be plucked using a pair of cosmetologist's tweezer. The strands of hair will be kept in different envelopes and labelled appropriately according to areas of the body from which they were plucked. Each strand in an envelope will be allocated with a specific identification number. The hair samples plucked will be processed. Then the samples will be mounted on specimen stubs with either a double stick cellophane tape or conductive paint on the ends. Long hairs will be divided into proximal (closest to the scalp), middle and distal (farthest from the scalp) and mounted. The hairs will be examined using the Scanning Electron Microscope from root to tip to observe the morphological characteristics and digital images will be captured.

Possible benefits

This research will be beneficial to the Albinism society by providing data as well information to their educational and research unit. Again, the study will provide a database which will help in the identification of hairs of persons living with Albinism.

Possible Risks and Discomfort

You will not be at any risk when participating in this research, though minor discomfort due to the plucking of the hair sample from the scalp or eyebrow.

Confidentiality

All information that will be obtained from you will be handled confidentially and used for the purpose stated for the study only. Your identity as a participant will not be disclosed to any unauthorized person. Only the researcher will have access to the research material which will be kept under lock. Participants will be identified by serial numbers or codes known to the principal investigator.

Cost and Compensation for Participation in Research

An amount of money (Ghc 50.00) will be given as compensation to individuals who will partake in the study. This amount will be given to participants in person after their hair samples have been taken.

Withdrawal from project

This research is voluntary and participant may give consent to partake in this study as a subject and can redraw anytime from the study without any penalty or victimization.

INFORMED CONSENT FORM

Principal Researcher: Abigail Owusua Yeboah

Name of Institution: Department of Anatomy, University of Ghana Medical School.

<u>Supervisory Team</u>

- Prof. Frederick Kwaku Addai
- Dr. John Ahenkorah
- Dr. Mrs. Juliet Ewool

Project Title: 'SCANNING ELECTRON MICROSCOPY (SEM) STUDY OF SCALP HAIRS OF PERSONS WITH AND WITHOUT ALBINISM'.

I have been invited to take part in this study for the research titled above. My role in this study is to allow the researcher take hair samples from my scalp and eyebrows to be used for the study.

I acknowledge that the purpose, research procedures, risk and discomforts as described above have been explained to me fully and that any questions that I have asked have been explained to my satisfaction.

I have been informed of the alternatives of participation in this study including the right to not participate. I also understand that I will benefit from this research and that my participation is totally voluntary and I have also been given enough time and opportunity to consider taking part in this study.

I have also been informed that the confidentiality of the information I will provide will be safeguarded and that my privacy and anonymity will be ensured in the collection, storage, and publication of the research material.

I,____have fully understood the aim, methods and conditions to participate in this study, I therefore consent to my participation.

________________________________ ________________________

Signature/Thumb print of Participant Date

__________________________________ ________________________

Researcher’s signature Date

APPENDIX TWO

DEPARTMENT OF ANATOMY

UNIVERSITY OF GHANA MEDICAL SCHOOL

COLLEGE OF HEALTH SCIENCES, UNIVERSITY OF GHANA

SCANNING ELECTRON MICROSCOPY (SEM) STUDY OF SCALP HAIRS OF PERSONS WITH AND WITHOUT ALBINISM

DATE:……………………………… ID NUMBER: PWA………………………

RESEARCH QUESTIONNAIRE

This questionnaire solicits for information, and subsequently, samples of scalp hair to be used in a research that seeks to determine the morphological profile of hairs of Ghanaian Albinos. It is purely for academic and health research purposes and nothing else. Your identity would be kept anonymous (never be disclosed) as we do not require your name on the form and the information treated confidential as much as possible. Please answer as accurately as possible. **Personal Details**

Please **Tick** the appropriate option

[1] What is your age range (in years)?

☐ 10 – 20 ☐ 21 – 30 ☐ 31 – 40 ☐ 41 – 50 ☐ 51 – 60 ☐ 61 – Above

[2] What is your highest level of formal education?

☐ No education ☐ Primary ☐ SHS ☐ Post-secondary ☐ Tertiary

☐ Other (please specify) ....

[3] What is your Occupation?

☐ Student ☐ Civil Servant ☐ Public Servant ☐ Farmer ☐ Housewife

☐ Other (please specify)..

[4] Are you a Ghanaian? □ Yes □ No

[5] Are both of your parents Ghanaians? □ Yes □ No

[6] Are your immediate grandparents Ghanaians? □ Yes □ No

[7] What is the current state of your scalp hair?

□ Virgin (untreated) □ Chemically treated (relaxed)