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The Evolution of Human Skin Pigmentation

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ABSTRACT OF THE DISSERTATION

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Human skin pigmentation is the most noticeable evidence of human evolution. Human skin pigmentation has progressively adapted to the local environment as humans have migrated from their central African origin. The purpose of this investigation is to explore the driving factors that have led to the diversity in skin pigmentation and explore the future direction of human skin pigmentation. With the advent of reflectometry-based instruments, researchers have been able to discover relationships between skin reflectance across populations and the average UV exposure experienced in their inhabited area. The reflectometry-based data also allowed researchers to compare the genetics between admixed populations and indigenous populations to discover new genes involved in skin pigmentation. The evolution of skin pigmentation is believed to be a result of the human need for previtamin/vitamin D₃, an adaptation that is most significant in childbearing women. With the significant impact that man has on the climate as well as the growing tendency of man to live indoors and in areas with low UV impact, the future evolution of skin pigmentation as well as how humans will adapt to such change remains a mystery.

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TABLE OF CONTENTS

| | |
|--|-----------|
| INTRODUCTION | 1 |
| HUMAN SKIN | 2 |
| Epidermis | 2 |
| Dermis | 4 |
| PRECURSOR OF HUMAN SKIN PIGMENTATION | 4 |
| EVOLUTION OF HUMAN SKIN TO ITS PRESENT CONDITION | 7 |
| CATALYSTS OF THE EVOLUTION OF HUMAN SKIN PIGMENTATION | 8 |
| Mechanism of Melanin | 8 |
| UV Radiation | 15 |
| Vitamin D Synthesis | 17 |
| Genetic Connection of Pigmentation | 20 |
| NEW RESEARCH FINDINGS | 27 |
| DISCUSSION | 31 |
| CONCLUSIONS | 33 |
| REFERENCES | 36 |
| APPENDIX | 42 |

Introduction

Throughout the years, scientists have been able to learn more about human skin and its adaptive abilities. It continues to evolve with time by constantly interacting with variables such as genetic inheritance, environmental changes, and endocrine factors (Jablonski 2012; Jablonski and Chaplin 2000).

The degree of exposure of naked human skin to different environmental conditions results in variance in skin color. For instance, Chimpanzees, the closest primate relatives of the humans, are born with uniformly pale skin, but their glabrous skin on their face and hands gradually becomes darkened after exposure to the sun and after a few years their face becomes spotted, before becoming uniformly dark just like their parents (Radhakrishnan et al. 2007). However, the skin in the rest of the chimpanzee body manages to remain pale as a result of being covered by a thick coat of hair (Radhakrishnan et al. 2007). Jablonski (2012) argues that since the ability to produce melanin pigment in melanocytes of the skin to counter ultraviolet radiation (UVR) is a shared characteristic of humans and their closest relatives (chimpanzees and the Old World Monkeys), it is logical to consider that this condition was present in their common ancestors six million years ago (mya).

In any case, the point of interest regarding the evolution of human skin revolves around four queries, such as

One, how the humans could evolve to its present hairless condition;

Two, how they could acquire skin that is resilient to a multitude of hazards that are emanating from the environment and living practices;

Three, how they could acquire the ability to produce melanin pigment in specialized cells that are known as melanocytes to combat UVR and survive considerable genotoxic stress; and

Four, how the skin manages to exploit UVR.

The goal of this review is to provide in-depth information regarding the four queries stated above and to formulate conclusions and predictions about the direction of human skin pigmentation for the future.

This review article will first examine the basic anatomy of the skin and its functions. Then the function and development of skin pigmentation will be explored.

Human Skin

The skin has several important functions in the body. It serves as an effective barrier against pathogens coming in contact with the body as well as a shield from the UVR from the sun. It is also an important site for the production of Vitamin D in the body. The human skin is made up of three layers, but only two will be discussed: a thin outer layer called the epidermis and a thicker inner layer called the dermis.

Epidermis

The epidermis is composed mainly of keratinocytes, which are composed of filamentous proteins called keratin (Jablonski 2004). It contains three types of dendritic cells: melanocytes, Langerhans cells and Merkel cells. Langerhans cells are associated with the immune system and are responsible for the induction of the immune system in response to foreign antigens (Jablonski 2004). Merkel cells are associated with nerve terminals and are involved with touch receptors.

The melanocytes are of most interest in this review since they are responsible for producing the skin's primary pigment, melanin. Melanocytes produce melanin in specialized cytoplasmic organelles called melanosomes, which vary in size and concentration depending on skin type and pigmentation (Jablonski 2004) (Figure 5). Melanosomes can also be found in keratinocytes. The number of active melanin-producing melanocytes varies over the surface of the body and activity can be increased as a result of exposure to UVR. Surprisingly, the number of melanocytes does not vary much from person to person (Young and Sheehan 2001). In darkly pigmented skin, melanosomes are large and are not clumped together whereas in lightly pigmented skin, the melanosomes are small and are clumped together (Jablonski 2004). The extent of skin coloration depends on a number of factors: (a) the total number of melanosomes in the melanocytes and keratinocytes and their degree of distribution; (b) the rate of melanin production; (c) the degree of melanin production in melanosomes; (d) the rate of transport and type of incorporation of melanosomes into keratinocytes; (e) degradation of melanosomes within keratinocytes; and (f) the person's age since the metabolic activity of melanocytes decreases over time (Jablonski 2004).

The epidermis can be subdivided into four layers from innermost to outermost: the stratum basale, the stratum spinosum, the stratum granulosum, and the stratum corneum (Figure 1). The outermost layer, the stratum corneum, consists of non-living keratinocytes made of lipid-depleted cells (Elias 2005). The stratum corneum functions as the primary barrier to microorganisms and toxic substances, water, and against most mechanical injuries caused by friction (Elias 2005) (Figure 1). Epidermal growth occurs by the outward displacement of differentiated cells through the epidermal layers until

they reach the stratum corneum (Elias 2005). The rate at which keratinocytes are produced is roughly equal to the rate at which the keratinocytes are lost at the stratum corneum. Across different races, variation exists in the thickness of the stratum corneum (Taylor 2002). The stratum corneum in black-skinned individuals is more compact than that of fair-skinned individuals (Taylor 2002). This compaction is believed to enhance the barrier protection functions of the skin (Taylor 2002).

Dermis

The dermis is a dense, fibroelastic tissue, composed of collagen and elastic fibers (Jablonski 2004). It contains two major types of sweat glands: eccrine and apocrine. The eccrine glands are distributed throughout the body while the apocrine glands are concentrated in the armpit, ear and the rectal area (Jablonski 2004). The sweat glands found in the dermis are especially important in thermoregulation of the body (Goldsmith 1991).

Precursor of Human Skin Pigmentation

Several research findings strongly suggest that the integument of the earliest hominids contained similar characteristics that are found in the integument of the chimpanzee, such as white or lightly pigmented integument. The exposed skin areas of chimpanzees vary considerably in their coloration due to their variance at species and subspecies level, but all of them experience an increase of facial pigmentation with age and exposure to UV radiation (Post et al. 1975). Another determinant of the primitive condition for primates in general is the fact that the epidermis of most nonhuman primates that remains hidden behind black hair is unpigmented due to the absence of active melanocytes in those regions, while the hairless areas of their body such as face,

eyelids, lips, pinnae, friction surfaces, and anogenital areas are pigmented (Montagna and Machida 1966). This observation strongly suggests that the exposure of hairless skin to UV radiation can induce melanogenesis and that the protohomonids had to go through similar evolution at some point (Montagna and Machida 1966; Montagna 1981).

Physiological models suggest that the evolution of hairlessness as well as the evolution of a sweating mechanism took place in accordance with the higher activity levels associated with the modern limb proportions and striding bipedalism (Montagna 1981; Schwartz and Rosenblum 1981; Wheeler 1984; Wheeler 1996; Chaplin and Jablonski 1994).

Body heat is a concerning factor for the primates as their brain is relatively large and functions optimally within a narrow thermal range and cannot tolerate high temperatures. For example, temperatures over 40°C in the body can be life threatening. Therefore, the evolution of an efficient cooling mechanism became essential for preventing hyperthermia. Primates have two basic ways through which they dissipate excess body heat: radiation and evaporation. Evaporation of sweat becomes more important at high ambient temperatures, and heavy body fur can slow down that process, thereby retarding body cooling (Frisancho et al 1981). Therefore, it is likely that hairlessness was a promoted trait amongst humans to promote body cooling.

The changing environmental conditions (from one of severe cold to one of significant warmth) allows one to deduce that early members of the genus *Homo* passed through a process of functional body hair loss and increases in the density of eccrine (watery) sweat glands (Jablonski 2004). This adaptation was necessary to facilitate sweating by the time that WT-15000 (Turkana Boy) traversed the woodland grassland habitats of the Lake Turkana Basin 1.5 million years ago (Jablonski 2004). The loss of

most body hair left the surface of the skin open to environmental assault, including UVR. Thus it is logical to assume that at this point of evolution, the human lineage developed permanent dark pigmentation over the entire body to protect from the harmful effects of high levels of UVR (Jablonski and Chaplin 2000).

It also appears that the evolution of the sweat glands in the transitional period significantly helped the integument maintain thermoregulation, as they increased in number especially in the areas that started losing hair. One of these areas includes the face, which is characterized by one of the most visible mechanisms of evaporative cooling (Cabanac and Caputa 1979; Falk 1990; Mahoney 1980). As a result of the importance of thermoregulation, the development of a whole body cooling mechanism is believed to have occurred. This prediction is based on the fact that the human brain grew over time in which temperature regulation had a significant effect on its growth (Vallender et al. 2008). From this prediction, one can see the evolutionary significance of the role of sweat glands in the skin with human development.

As a result, naked skin acquired the ability of providing a thermoregulatory advantage to the body by reducing total thermal load that requires evaporative dissipation (Chaplin and Jablonski 1994). During the transitional period between hairy-skin and hair-less skin, the decreases in the density of body hair and increases in the density of sweat glands together increased the need to protect subepidermal tissues from harmful effects of UVR (Jablonski 2012). This, in turn, led to the evolution of skin pigmentation/melanization. An increased rate of melanization among humans solved the above issue (Jablonski and Chaplin 2000). It is believed that body hair functioned in protecting the skin from the detrimental effects of UVR (Jablonski and Chaplin 2000).

Evolution of Human Skin to its Present Condition

Although it is impossible to determine the exact period, several investigations suggest that at the beginning of the hominid lineage, its members had mostly unpigmented or lightly pigmented skin, which was covered with dark black hair, very similar to the modern chimpanzees (Jablonski 2004). The evolution of the naked and darkly pigmented skin took place within the evolutionary phase of the genus *Homo*. It was around that time the early members' dark epidermis started protecting their sweat glands from UVR-induced injury and thereby ensuring the integrity of somatic thermoregulation. The above speculation facilitated the emergence of the hypothesis that highly melanized skin in those early members helped them counter UVR-induced photolysis of folate, which is a metabolite essential for normal development of the embryonic neural tube and spermatogenesis (Branda and Eaton 1978). This factor highly contributed to the individual reproductive success at that time (Branda and Eaton 1978; Post et al 1975).

After migrating from the equatorial regions, depigmentation in *Homo* is believed to have occurred in varying degrees, as they had to accommodate for the significant difference in UVR intensity at northern regions in order to continue synthesis of previtamin D₃ (Jablonski and Chaplin 2000). This was especially important for females since they required more vitamin D₃ during pregnancy and lactation (Jablonski and Chaplin 2000). Thus the causes of varied states of pigmentation are a result of migration, exposure to different degrees of UVR (and other environmental factors), cultural adaptations and diet, besides genetic intervention caused by natural selection (Jablonski & Chaplin, 2000) (Figure 7).

Interestingly, this pattern of heavy pigmentation of individuals living near the equator is also seen in endothermic animals living near the equator. This zoological rule is called Gloger's rule (Burt and Ichida 2004). One theory behind this trend is that in the case of birds living in equatorial regions, darkly pigmented feathers are most resistant to hair-degrading bacteria which are able to breed particularly well in humid weather (Burt and Ichida 2004).

Catalysts of the Evolution of Human Skin Pigmentation

Four factors can be considered as the major catalysts of the evolution of human skin pigmentation. They are: mechanism of melanin, UVR, vitamin D synthesis, behavior of melanin, and genetic influence.

Mechanism of Melanin

Human skin contains two types of melanin: the brownish-black eumelanin and the reddish-yellow pheomelanin (Rees and Harding 2012). The synthesis of melanin occurs by the conversion of DOPA to dopaquinone by the tyrosinase enzyme (Rees and Harding 2012). Dopaquinone can either combine with cysteine to produce pheomelanin or it is converted to leucodopachrome to form eumelanin (Rees and Harding 2012). High concentrations of eumelanin are found in darker skin phenotypes including tan skin (Rees and Harding 2012). Pheomelanin can be found in high concentrations in red-haired northern Europeans as well as Native Americans and East Asians (Jablonski 2004). The distribution of melanin in lighter skin is characterized by clusters of melanosomes in keratinocytes, while in darker skin, melanin is distributed individually in keratinocytes, which allows for efficient light absorption (Miyamura et al. 2006) (Figure 5).

Melanosomes are the organelles that store the melanin pigment. The production of

melanin is regulated by pigmentation genes, hormones and UVR (Rees and Harding 2012). In human skin and hair, melanin is actively transferred to keratinocytes for distribution towards the surface of the skin and hair (Miyamura et al. 2006) (Figure 5).

Melanin acts as the change agent to skin by creating variation in its visual appearance. Factors such as countering UVR into the skin, regulating the penetration of sunlight, and cultural practices can cause variation in cutaneous melanin pigmentation (Figure 7). It is believed that the natural selection for organisms with melanin is believed to be a result of the protection that melanin provides to the organism in partially protecting against UVR and the protection against damage to DNA that the UVR cause (Holick 2007). The evidence of highly melanized skins of native populations in the tropical region providing higher degrees of protection against harmful effects of UVR (such as sunburn, skin cancer and nutrient photolysis) is well documented (Fitzpatrick 1965; Branda and Eaton 1978). Also, the relationship of more lightly pigmented skin in the populations inhabiting latitudes closer to the Arctic region demonstrates evidence of adaptations to the lower UVR experienced in those areas. This lends further support to the influence of UVR on skin pigmentation (Jablonski 2004). Other factors such as regulation of frostbite-sensitivity, disease prevention, thermoregulation, and concealment have also been identified as contributors to skin pigmentation (Post et al. 1975; Wassermann 1974; Roberts and Kahlon 1976; Cowles 1959).

Since reproductive success is threatened by UVR-induced sunburn or skin cancer, some researchers argue that melanin pigmentation can be considered as adaptive (Blum 1961). It has also been argued that skin pigmentation is a byproduct of selection that acts on the first functions of pigmentation genes, such as regulating metabolic pathways (Deol

1975). An alternative view is that sexual selection played a role in the evolution of skin pigmentation based upon the selection factors that may have led to increased preference for a mate with a particular skin tone (Jablonski 2004). However, the most widely accepted function of melanin is that it is a photoprotective filter that reduces the penetration of all wavelengths of light into subepidermal tissues (Daniels 1959; Kaidbey et al. 1979).

There are various interactions that can occur between the outermost layer of the skin, stratum corneum, and sunlight. One such form results in the light entering the stratum corneum and changing its direction of travel due to its interaction with melanin dust in the stratum corneum and causing partial/total absorption (Daniels 1959) (Figure 5). As the sunlight continues traversing deeper layers and experiences additional scattering, it eventually enters the epidermis and encounters melanin that is packaged within melanosomes (Daniels 1959). The effect of sunlight on the skin varies due to the varied distribution of melanin throughout the body. Pheomelanin is not typically present in high concentrations like eumelanin is because of pheomelanin's rapid degradation after exposure to UV as well as its limited photoprotective properties compared to eumelanin (Jablonski and Chaplin 2000). The highest concentration of melanocytes exists at the upper dorsal skin while the concentration is lower in other areas (Miyamura et al. 2006). Another study confirmed that high concentrations of melanocytes exist in the back and shoulders with lower levels at other areas (Whiteman et al. 1999).

The melanin dust of the stratum corneum, which is considered a degradation product of the melanosomes, performs the necessary function of attenuating radiation at the surface level of the skin to protect its deeper layers (Figure 5). Otherwise, the

majority of the melanin remains packaged in intact melanosomes that reside at a deeper level of the skin known as the Malpighian layer. Throughout the Malpighian layer of the epidermis, these organelles are distributed to keratinocytes by the dendritic processes of melanocytes (LaBonne & Bronner-Fraser, 1998).

The melanocytic development in humans begins with the migration of the melanoblast from the neural crest during embryogenesis (Eisenger and Marko 1982). The commitment of neural crest cells to the melanogenic lineage facilitates melanoblasts, which are capable of migrating to various destination sites and differentiating to melanogonia and finally maturing melanocytes (Eisenger and Marko 1982). The dendritic processes of differentiated melanocytes are located in the basal layer of the epidermis, where they remain interspersed between neighboring keratinocytes. Contact between the dendrites of melanocytes and keratinocytes play an essential role in transferring the melanosomes that produce melanin (Eisenger and Marko 1982). In a human body, one epidermal melanocyte usually makes contact with 30–40 keratinocytes (Eisenger and Marko 1982). The transfer of melanin containing melanosomes to the keratinocytes occurs with the help of cdc42, a small GTP-binding protein (Scott et al. 2002). Cdc42 mediates filopodia formation between melanosomes and keratinocytes and, ultimately, the endocytosis of the melanosome to the keratinocyte (Scott et al. 2002).

Such interaction enables the melanocyte to transfer melanin to the keratinocytes and, as a result, skin color and protection from UV radiation can occur. The melanocytes and keratinocytes together form an “epidermal melanin unit,” a symbiotic interaction that also occurs between bulb melanocytes (Ortonne and Prota 1993). The distribution system of melanin between melanocytes and keratinocytes helps ensure superior

photoprotection of highly melanized skin, since it facilitates absorption and scattering of UVR. Melanin is able to absorb UVR by reducing the amount of UVR that penetrates the skin. The degree of protection from UV rays largely depends on the density and distribution of melanosomes within keratinocytes in the basal and parabasal layers of the epidermis as well as the presence of specks of melanin dust in the stratum corneum (Kaidbey et al. 1979; Eisenger and Marko 1982).

The degree of pigmentation of melanocytes in an individual affects its response to UVB irradiation. In heavily pigmented melanocytes of darker skin individuals, the melanocytes have greater ability to grow after getting exposed to UVB radiation than lighter skinned individuals (Barker et al. 1995). However, in both light and dark skinned individuals, the melanocytes were inhibited and the expression of the tumor suppressor p53 protein occurred (Barker et al. 1995). In lighter skinned individuals, the expression of p53 was significantly longer and more pronounced than in dark skinned individuals. The prolonged activity of p53 in light-skinned individuals is believed to be due to the repair of DNA damage from UVB (Barker et al. 1995). This prolonged activity is an example of an adaptation of light-skinned individuals to UVB radiation and can be viewed as an effect of skin depigmentation. This prolonged activity likely means increased consumption of energy in light-skinned individuals and a necessity for the individual to obtain more nutrients.

As was noted in the study by Barker et al. (1995), the effects of UVB exposure are usually harmful except for its beneficial role in vitamin D synthesis. Excessive UVB exposure can cause sunburn and damage to the sweat glands, which in turn can cause suppression of sweating and severe disruption in the thermoregulation process. It can

also cause several short-term harmful effects such as poor threshold of pain, discomfort, vesiculation, desquamation, and nutrient photolysis (Branda and Eaton 1978). Sustained periods of such degenerative changes in the dermis and epidermis can result in skin cancers (Daniels 1964; Branda and Eaton 1978).

The detrimental effect that UV radiation can have on the stability of DNA and ultimately reproduction led to the theory that the protection of nutrient photolysis from UV absorption (instrumental in reproductive success) acted as the main selective agent in the evolution of skin pigmentation of individuals (Branda and Eaton 1978) (Figure 6). The particular nutrient of interest that is believed to be an important selective agent for the evolution of skin pigmentation is folate. Deficiencies in folate are known to cause anemia, infertility, maternal mortality and fetal wastage (Branda and Eaton 1978). The detrimental actions that occur in the body as a result of overexposure to UVR suggests that the emergence of the need to protect sweat glands and to maintain the thermoregulatory capability also resulted in increased melanization (Branda and Eaton 1978).

Folate is derived from folic acid, which is essential for the development of the human body. It is an essential nutrient for nucleotides and therefore, DNA biosynthesis (Fleming and Copp 1998). Folate also acts as an essential ingredient for bone marrow maturation and red blood cell development, where its deficiency causes multiple fetal anomalies such as malformations of the eye, central nervous system, palate, lip, gastrointestinal system, aorta, kidney, and skeleton. This is due to the fact that folate plays an important role in purine and pyrimidine biosynthesis (Fleming and Copp 1998). Defective folate can also cause neural tube defects (NTDs), which consist of a family of

congenital malformations that emanate from incomplete neurulation and are expressed as deformities of varying severity (Fleming and Copp 1998). For example in the case of *craniorachischisis totalis*, the entire neural tube fails to close, which causes spontaneous abortion (Fleming and Copp 1998).

Folate shows maximum sensitivity to ethanol and UV radiation, where the negative impact of ethanol on folate has long been identified as a problem of chronic alcoholics (Tamura and Halsted 1983). The negative impact of UV radiation was observed in the instances of quick degradation of folate under sunlight or UV light (Kaunitz and Lindenbaum 1977) (Figure 6). The significant decline in serum folate level after its exposure to simulated natural sunlight in-vitro also demonstrated photolysis (chemical process by which molecules are broken down into smaller units through the absorption of light) of folate (Branda and Eaton, 1978). As a result of exposure to sunlight, folate photolysis has also been noted to cause NTDs in amphibians. The damaging effects of folate photolysis observed in other species further emphasize the role of folate in developmental processes. Also, the significance of protecting folate becomes even more evident when one learns about the crucial role of folate in spermatogenesis (Cosentino et al. 1990). Serious depletions of folate can significantly decrease sperm production.

The aforementioned observations about the significance of folate and the detrimental effects that occur when there are deficiencies in folate indicate that protection against UVR is crucial for maintaining adequate folate levels. The importance of protecting folate is believed to be a driving force for increases in melanin concentration in the human body. The low prevalence of severe folate deficiency and NTDs among

African and African American individuals with low nutritional status but having highly melanized skin strongly supports the fact that melanin protects against folate photolysis (Lawrence 1983).

UV Radiation

Out of the sun-emitted electromagnetic radiation, there are three types of UVR that affect the skin: the short wavelength UVC (100-280nm), the middle wavelength UVB (280-315nm) and long wavelength UVA (320– 400 nm) (Figure 6). These three types of wavelengths penetrate the atmosphere and highly influence the biological environment of the Earth. Fortunately, the high energy UVC gets completely absorbed by the ozone and does not reach the Earth's surface. The photochemical effect occurs when the solar radiation gets absorbed, in which an effective photon of radiation travels from the sun to the body's surface through the atmosphere. The air mass is essential to the transmission of UV radiation. It is determined by the time of day, season, latitude, and altitude of the air with scattering being greatest at shorter visible wavelengths (Daniels 1964). The transmission of UV and visible radiation to the Earth's surface are also determined by absorption in the ozone layer, clouds, dust, haze and various organic compounds (Daniels 1964).

Before the arrival of remote sensing technology, mathematical models served as the instrument to measure the intensity of UV radiation at the Earth's surface and the erythral response (redness of the skin) of human skin to UVR (Paltridge and Barton 1978). Although these models were able to predict UVR intensity on Earth, they were incapable of providing direct measurements of solar elevation, ozone and aerosol amounts in the atmosphere. Those problems have been eliminated with the usage of remote sensing technology, which can directly measure the UV radiation reaching the

Earth's surface, while measuring ozone concentration and scene reflectiveness, such as cloud conditions, snow, and ice cover (Herman and Celarier 1996).

With this new technology, researchers have begun exploiting the use of remote sensors in their investigations with skin pigmentation. For example, Jablonski and Chaplin (2000) have utilized the direct measurements of UVR at the Earth's surface, and have combined it with data regarding skin pigmentation to discover a correlation between the two. They found that there was no significant difference between the northern and southern hemispheres regarding the annual erythemal (sunburn) means for UVR, but there were significant differences between them at the summer and winter solstices, the magnitude of which could be predicted from the perihelion effect (maximum proximity of Earth to the sun, which varies during seasons) (Jablonski 2012). Another conclusion reached by Jablonski and Chaplin was that the hemispheric differences in skin color is caused by factors like dense population in the high annual radiation zones and less population in the similar zones of the northern hemisphere (Jablonski and Chaplin 2000). It was discovered that individuals living in the northern hemisphere tend to have lighter skin than individuals living at equivalent latitudes in the southern hemisphere (Chaplin and Jablonski 1998). This was determined to be a result of the greater UVR exposure that the southern hemisphere receives in comparison to the northern hemisphere and the role that melanin has in dealing with increased UVR. By analyzing the differences in the distribution of land mass on Earth, Chaplin and Jablonski (1998) were also able to conclude that the evolution of skin pigmentation occurred to a greater extent in the northern hemisphere because there is more land and greater variation in UVR exposure.

Vitamin D Synthesis

The human body cannot survive without vitamin D₃, as it is an essential ingredient for normal growth, calcium absorption, and skeletal development. Also, lack of this vitamin can cause severe health conditions such as immobilization and pelvic deformities (and thereby preventing normal childbirth) and in extreme cases, death (Neer 1975). There is no consensus on the necessary levels of vitamin D that the average person needs per day, but most experts define vitamin D deficiency as a 25-hydroxyvitamin D level (discussed below) of less than 20 ng per milliliter (Holick 2007). Females require it in more significant amounts during pregnancy and lactation periods as they experience an enhanced maternal absorption of calcium that is used in building the fetal and neonatal skeletal system (Whitehead et al. 1981).

In general, the process by which vitamin D is synthesized begins with the casual exposure to sunlight. This initiates a process in the body, where the UVB photons convert 7-dehydrocholesterol in the skin into previtamin D₃ (Loomis 1967) (Figure 6). Subsequent isomerization of the previtamin produces vitamin D₃ at body temperature (Loomis 1967). The vitamin D₃ that is produced as a result of exposure to light is further metabolized in the liver to 25-hydroxyvitamin D, which is used to determine the vitamin D levels in a person (Holick 2007). The 25-hydroxyvitamin D is then metabolized in the kidneys to its active form, 1,25-dihydroxyvitamin D (Holick 2007). The production of vitamin D₃ only occurs with exposure to UVB. The uses of dietary supplements to combat Vitamin D₃ deficiencies are also helpful as well as consumption of milk and fish, both of which are high in the vitamin (Holick 2007). The early human ancestors, whom were completely covered with hair, were able to obtain their necessary exposure of UVB

to synthesize vitamin D with the exposure of hairless regions on their body (Jablonski and Chaplin 2000).

It is generally accepted that increased amounts of melanin enables the maximization of the synthesis of previtamin D₃ since the increased melanin enables the body to increase the time of exposure to UVB light (Holick et al. 1981). However, having too much melanin, like in deeply melanized skin, becomes maladaptive when high concentration of melanin blocks UVB from entering the skin and does not allow for sufficient amounts of previtamin D₃ synthesis in the skin to occur (Loomis 1967; Holick et al. 1981). It has also been observed that if the duration of UVB exposure is less than is necessary to catalyze previtamin D₃ synthesis, the risk of suffering from vitamin D₃ deficiency and its manifestations such as rickets, osteomalacia, and osteoporosis, significantly increases (Fogelman et al. 1995). This has been demonstrated in individuals that have migrated from India, where heavy skin pigmentation is common, to the United Kingdom, where UV levels are significantly less than in India (Jablonski and Chaplin 2000).

Although we now believe that skin pigmentation has generally evolved throughout the years for the necessary synthesis of Vitamin D₃, there were many early theories as to why skin pigmentation occurs. For example, Loomis (1967) once proposed two points: depigmentation of the skin was a part of adaptation for individuals living outside the tropic region and that increases in melanin concentration were important in preventing UVB-radiation induced vitamin D₃ toxicity due to over-synthesis of previtamin D₃. In support of his argument, Loomis described samples of humans with lightly melanized skin living comfortably under low average amount of UVB radiation

and humans with highly melanized skin living comfortably in high UVB-radiation zones (Loomis 1967).

However, Loomis' hypothesis regarding depigmentation of human skin as a result of humans living at higher altitudes outside of the tropics was challenged by Robins (1991), who noted that in spite of very long, cold winter seasons experienced by humans living at higher altitudes in the north, the early *Homo* could manage without experiencing hypovitaminosis, as they are able to store Vitamin D in body fat and muscle accumulated during the times of UVB exposure in higher latitudes for use during times of limited UVB exposure. The use of the stored Vitamin D₃ is particularly useful during the winter, when individuals experience significantly less UVB radiation exposure (Holick 2007). This finding suggests that skin depigmentation may not be necessary. Robins (1991) also notes that deficiencies in Vitamin D are a result of "industrialization, urbanization and overpopulation" in which individuals that suffer from deficiencies in Vitamin D are typically living in urban areas where they tend to get limited amounts of UVB.

Loomis' hypothesis about increased melanin concentration as a means to prevent hypervitaminosis of Vitamin D under high UVB radiation was challenged and has been disproven. Researchers point at the lack of evidence regarding deeply pigmented skin working as an agent of preventing hypervitaminosis of vitamin D under high UVB radiation. Instead, they showed that vitamin D toxicity was prevented by a ceiling effect on previtamin D₃ synthesis combined with *in vivo* photolysis of vitamin D₃ itself so that humans could never undergo hypervitaminosis of vitamin D naturally (Holick et al. 1981). Robins also refuted Loomis' claim by showing that vitamin D toxicity is an

outcome of overdose of vitamin supplements and that there is no evidence of natural occurrence vitamin D₃ intoxication (Robbins 1991).

Genetic Connection of Pigmentation

Before adopting reflectometry-based instruments for measuring skin pigmentation, the researchers utilized subjective assessments by using reference frames or scales created by Felix von Luschan (1927) or Thomas Fitzpatrick (1975). These two scales provided rough categorical estimates along with inter-observer error. It is obvious that such data are unsuitable to conduct quantitative genetic analysis (Quillen and Shriver 2011).

Even though individuals possess approximately the same number of melanosomes, more melanin is found in the melanosomes of darkly pigmented individuals, where their melanosomes also appear larger (Sturm et al. 1998). Such differences occur due to the variations in cellular structure and biochemical pathways, which form the basis of pigmentary differences among groups. Apart from the variation that arises from cellular structure and biochemical pathways, a significant number of variations in skin color occur due to the mutations in several genes that compose the pigmentation pathway, including tyrosinase activity (encoded by the TYR gene) (Fuller et al. 2001).

Von Luschan's chromatic scale is a method of classifying skin color (Table 1). The equipment for the scale consists of 36 opaque glass tiles, which were used to compare to the subject's skin in areas not exposed to UV (such as under the arm) (von Luschan et al. 1927). The von Luschan scale was also used to paint a better picture about the different skin pigmentation that existed throughout the world and how the pigmentation generally decreases as one travels further from the equator (Figure 4).

On the other hand Fitzpatrick (1975) classified the skin color into six categories to identify the response of different types of skin to UVR (Table 2). This is mostly used in dermatologic research on the color of skin. This scale measures several components such as genetic disposition, reaction to sun exposure and tanning habits.

The basic difference between the von Luschan Scale and the Fitzpatrick Scale is that the von Luschan scale categorizes skin color on the basis of regional distribution, while the latter classifies individuals by their actual skin tone. Nevertheless, both scales provide subjective data assessment, which cannot work as clear inputs to genetic analysis of skin pigmentation.

However, the advent of reflectometry-based instruments provided a new avenue of research and investigation on the evolution of human skin pigmentation. Such measurements enabled the investigators to estimate quantitative genetic underpinnings of this trait and to establish the significance of admixed human populations in skin color research (Quillen and Shriver 2011). Researchers Harrison and Owen (1964) used reflectometry-based measurement to measure reflected light across the visible spectrum in relatively unadmixed West Africans and Europeans, as well as in four admixed (those formed by gene flow between two or more genetically distinct populations) groups (F1 hybrid, European backcross, West African backcross, and F2 hybrid).

A large number of investigations have been conducted to identify genes involved with skin pigmentation. These investigations were conducted in recently admixed populations mainly with West African/European or Indigenous American/European parental populations, instead of involving genome-wide association studies on non-admixed populations. Admixed populations typically have intermediate degrees of

pigmentation. According to Harrison and Owen (1964), admixed populations are very useful in enhancing the understanding on pigmentation differences among various populations, as one finds alleles at many of the functional loci are either fixed or nearly fixed. Investigations of non-admixed populations would be more difficult to interpret since the skin pigmentation would be constant amongst the population and loci involved with skin pigmentation would not be able to be isolated.

The investigators expanded the research on the admixed populations by using data from F1, backcrossed, and F2 individuals of the admixed populations. On the basis of their variance across different loci, they predicted that at least six to eight genes were involved in generating skin color differences between European and West African populations (Fuller et al. 2001). In a more recent investigation that considered contemporary admixed populations that had undergone admixture for many generations, the investigators were able to identify 10 genes that contributed to the population-level skin color differences between European and West African populations (Parra 2007).

Admixed population analyses have proven to be substantially more useful in producing better pictures of the evolutionary architecture of human skin pigmentation rather than utilizing the genome-wide association study approach (Quillen and Shriver 2011). Methods other than admixed population analysis were also used. Lamason et al. (2005) determined that a mutation in SLC24A5 with the golden phenotype in zebrafish significantly influenced pigmentation. After discovering this gene, Lamason et al. investigated this gene amongst admixed populations. In humans, the HapMap project discovered an amino acid substitution in human homolog (SLC24A5*Thr111), which has been identified as the producer of the single largest effect on skin color differences

between the Europeans and the West Africans (Lamason et al. 2005). It is interesting to note that this mutation is fixed across the European regions, while proving a rare phenomenon (only 2.5% occurrence) in East Asia (Lamason et al. 2005). This huge difference suggests that mutations involved in light skin pigmentation are kept confined within a particular population and are not shared with other populations. Another gene, SLC45A2, was also identified as contributing to skin pigmentation as a result of admixed population studies (Lamason et al. 2005).

With the help of genetic analysis, deductions drawn from functional anatomy and thermophysiology regarding hair loss and pigmentation found support for the function of melanin with the discovery of the melanocortin 1 receptor locus (*MC1R*). The *MC1R* can be traced back as far as 1.2 mya. The loss of function of the alleles at the *MC1R* locus are involved with the expression of fair skin, freckling, and red hair phenotypes (Barsh 2003). The activation of the *MC1R* promotes the synthesis of eumelanin (black-brownish melanin) at the expense of pheomelanin (red-yellow melanin) synthesis (Barsh 2003). Since *MC1R* was present early on in the human evolutionary history, one can predict that the evolutionary pressure for protective melanin pigmentation was very high at that time and the variation in the *MC1R* gene had disappeared over time due to negative selection (the selective removal of alleles that are deleterious) and the difference in survival among individuals during that time (Rogers et al. 2004). This allows one to hypothesize that the members of the genus *Homo* living in Africa around 1 mya, from which all modern humans evolved, likely had naked and darkly pigmented skin. This hypothesis is further supported by the finding that the *MC1R* gene has limited allelic

diversity in African population samples suggesting that MC1R may have a significant role in dark skin pigmentation (Barsh 2003).

Earlier research into genes related to human skin pigmentation revolved around studies of extreme phenotypes like albinism, the absence of expression of melanin as a result of a defect or absence of tyrosinase in the synthesis of melanin (Barsh 2003). By comparing the genotype of albinos from a darkly pigmented population with other members of the same population, researchers were able to identify particular genes involved with human skin pigmentation (Barsh 2003). The genes implicated in albinism include the TYR, P and MATP genes (Barsh 2003).

To determine the role of SLC24A5*Thr111 allele found in European populations in melanogenesis, Ginger et al. (2008) inserted it into the DNA of cultured melanocytes and resultantly, the modification in the trans-Golgi network-associated protein, NCKX5, showed a significant decrease in cation exchange and down regulation of melanin production (Quillen and Shriver 2011). This discovery led to Ginger et al. (2008) to hypothesize that this mutation is capable of changing the acidity in the trans-Golgi network, and could significantly effect the distribution of pre-melanosomes throughout the body (Quillen and Shriver 2011).

This new line of research greatly contributed to the understanding of genetics of human skin color, which is considered as the most rapidly evolving trait in humans (Quillen and Shriver 2011). Because of the new knowledge, the understanding of the genetic basis of normal pigmentation variation has increased to a great extent, where the researchers have been able to identify as many as 11 genes as significant factors of skin pigmentation levels among various human populations (Parra 2007; Sturm 2009).

The above admixture population based investigations are supported by recent studies of genomic selection at these pigmentation genes, where the distributions of SLC24A5, SLC45A2, and other skin pigmentation genes show a greater variance than what is found for most human genes and phenotypes (Quillen and Shriver 2011). Due to the great variance, researchers have begun to wonder about the types of selective pressures that occurred throughout time that would give rise to such variance. Researchers Harrison and Owen (1964) were among the first to find an answer regarding this great variance by examining skin reflectance levels (Quillen and Shriver 2011). Recent scans across West African, East Asian and Northern European populations for selection across the human genome indicated a strong and repeated selection on skin pigmentation genes (Figure 2) (Quillen and Shriver 2011).

It is suggested that the significantly higher number of genes that were selected for in East Asian and European populations is a result of their relatively recent migration from Africa in the last 50,000 years (Quillen and Shriver 2011) (Figure 2). The significantly higher number of genes that were detected in these two migrating populations compared to the West African population may be due to the difficulty of being able to determine earlier selection (Quillen and Shriver 2011) (Figure 2).

The above data indicates independent evolution of light skin pigmentation among European and East Asian populations, which is fairly indicative of the fact that shared phenotype does not emerge from a shared ancestral mutation (Quillen and Shriver 2011). This independent evolution of skin pigmentation has already been shown due to the previous mention of SLC24A5*THR111 being nearly confined to the European population.

Altogether, most researchers agree that the darker skin pigmentation evolved due to its involvement of reducing photolysis of folic acid, and, as a result, protection from NTDs, and contributing to DNA replication and repair processes (Quillen and Shriver 2011). Folic acid has been noted to prevent up to 70% of NTDs in humans (Jablonski and Chaplin 2000). A point that researchers have begun to disagree on is whether the evolution of lighter skin pigmentation occurred as a result to synthesize vitamin D, since researchers disagree on when Vitamin D began contributing to fitness (Jablonski and Chaplin 2000).

Although researchers disagree on the basis of the evolution of lighter skin pigmentation, researchers do agree that the selection pressure on skin pigmentation has been equally strong as it is with genes that are assigned to manage immunity, reproduction, and food intake—all processes that are essential for fitness (Quillen and Shriver 2011). This observation is based on the fact that pigmentation genes are more than twice as likely to show signs of selection than randomly selected genes in European and Chinese populations (Quillen and Shriver 2011).

However, there is still much to know about the relationship between genes and skin pigmentation. The continuous discovery of more information about the interworkings of genes and skin pigmentation will help to clarify the bends and leaps of selection for skin pigmentation. For example, it is still a mystery as to why there is genetic variation among the population of genes implicated in human skin color variation. Similarly, the roles of more than 350 putative pigmentation loci, identified in mouse models and catalogued in the international federation of pigment cell societies (IFPCS), in human skin pigmentation remains to be known (Quillen and Shriver 2011).

To better understand the relationship between genes and skin pigmentation, it is agreed that accurate and objective measurement techniques need to be used to determine the total picture of the ramifications of human evolution in shaping the genetic architecture and distribution of human pigmentation. The self-reports and subjective assessments may be helpful to identify genes for some phenotypic traits (blond hair, green eyes, excessive skin pigmentation), but the analyses of skin using reflectometry at specific wavelengths provides quantitative data that can be used to compare skin pigmentation results over a wide range of populations (Quillen and Shriver 2011).

New Research Findings

Jablonski and Chaplin (Jablonski and Chaplin 2000) present new evidence from their remote-sensing-aided investigations on the evolution of human skin pigmentation. Their findings support the hypothesis that variations in skin color are adaptive; they are related to the regulation of UVB radiation penetration in the integument and its direct and indirect effects on fitness. The experiments performed were the first of its kind, where the distribution of the skin colors of indigenous people relative to UVR levels was tested quantitatively (Jablonski and Chaplin 2000). Before that, some recent studies on the relationship between environmental variables and the skin color of indigenous populations used skin reflectance spectrophotometry and demonstrated a strong relationship with latitude and prompted the researchers to interpret that finding as a reflection of the crucial role of UVR in determining the skin color (Roberts and Kahlon 1976). As a result, Jablonski and Chaplin analyzed data on the minimum erythemal dose of UV (UVMED) levels at Earth's surface to determine the geographic distribution of the potential for previtamin D₃ synthesis (Jablonski and Chaplin 2000). The duo also used

the data on UVMED levels to analyze the relationship between surface UV radiation levels and skin color reflectance for indigenous populations (Jablonski and Chaplin 2000).

During their analysis of UVMED levels and its relationship with skin pigmentation, Jablonski and Chaplin compiled a database of skin reflectance from numerous sources that comprised of samples designated as male, female, and both sexes, and for reflectance at 425 nm (blue filter), 545 nm (green filter) and 685 nm (red filter), for the upper inner arm site (Jablonski and Chaplin 2000). Following Relethford's (2002) finding that relationship between UVR and skin reflectance in the northern hemispheres differs from that of southern hemispheres, Jablonski and Chaplin conducted analyses for both hemispheres together and for each hemisphere separately. In the process, they found the annual UVMED as equal for both hemispheres, though the seasonal distribution of UVB radiation was different. Individuals living in the northern hemisphere were exposed to significantly less UVB than individuals living in the southern hemispheres. The hemispheres also differed in their respective land surface area and degree of land mass connectivity with the northern hemisphere having significantly more land (Jablonski and Chaplin 2000). When analyzing the annual UVMED distribution throughout the world, Jablonski and Chaplin were able to divide the total area into three zones on the basis of their different potentials for UVB-induced vitamin D₃ synthesis (Figure 3):

- A. Zone 1 comprised of an area approximately 5° north of the Tropic of Cancer to approximately 5° south of the Tropic of Capricorn, where previtamin D₃

could be synthesized in lightly pigmented skin as a result of exposure to UVB throughout all months of the year;

- B. Zone 2 comprised of an area in which the average daily UVMED for at least one month was not sufficient to produce previtamin D₃ in lightly pigmented skin. Accordingly, a vast area of the northern hemisphere fell within this zone;
- C. Zone 3 comprised of the area in which the daily UVMED averaged over the whole year was not sufficient to catalyze previtamin D₃ synthesis in lightly pigmented skin. In other words, it was the zone in which previtamin D₃ synthesis resulting from UVB exposure, as averaged over the course of a year, was not sufficient to meet minimum physiological requirements.

The data represented in Figure 3 were determined on the basis of the potential for previtamin D₃ synthesis in light skin (data on dark skin was unavailable) (Jablonski 2012). Data about the time of UVB exposure to maximize pre-vitamin D₃ synthesis was used to determine the geographical zones in which annual UVMED was not sufficient to catalyze pre-vitamin D₃ synthesis in highly and moderately melanized skin (Table 3). The researchers realized that since it takes nearly 5 times longer for highly melanized skin (Type VI) to maximally produce previtamin D₃ than it does for lightly melanized skin (Type III) means that exposure to UVB for heavily pigmented individuals is especially important (Jablonski and Chaplin 2000) (Table 3). As mentioned earlier, the landmass in the northern hemisphere is significantly higher than in the southern hemisphere, which ultimately means that lighter skinned individuals have more areas to

inhabit. The significantly more areas to inhabit in the north are believed to be the reason why there are numerous degrees of skin pigmentation in the world.

From skin reflectometry experiments, Jablonski and Chaplin (2000) have determined that skin reflectance has strong relationships with absolute latitude and UV radiation levels. The strongest correlation between skin reflectance and UV levels can be observed at 545 nm, near the absorption maximum for oxyhemoglobin. Since the strongest correlation was observed at the absorption maximum for oxyhemoglobin, this data suggests that one of the main roles of melanin pigmentation in humans is to regulate effects of UV radiation on the contents of cutaneous blood vessels that are located in the dermis (Jablonski and Chaplin 2000). It is believed that the absorption maxima of oxyhemoglobin being at 545nm is to balance the requirements of preventing folate photolysis and previtamin D₃ synthesis (Jablonski and Chaplin 2000).

Another interesting new finding is that females tend to be lighter skinned than males in all populations for which skin reflectance data were available for males and females (Jablonski and Chaplin 2000). This discovery further confirms the importance of vitamin D₃ for females during periods of pregnancy as mentioned earlier. The finding that women tend to have lighter skin than men can also be explained by the fact that women are usually indoors most of the time, out of the exposure to UV (Figure 7). One interesting point to note about this discovery is the influence of sexual selection. If sexual selection were a driving force for the lighter skin in females, one would have to conclude that there was some sort of universal preference for males of females that had lighter skin (Diamond 1991). However, it is more likely that lighter skin pigmentation

among females began as an advantageous trait in fitness, which became reinforced by culture (Jablonski and Chaplin 2000) (Figure 7).

Discussion

The findings from Jablonski and Chaplin's investigation corroborates with clinical findings that show a strong relationship between various manifestations of hypovitaminosis D₃ (producer of rickets, osteomalacia, and osteoporosis) and the moderately to deeply pigmented humans (Jablonski 2012). This relationship was especially evident when the opportunities to achieve endogenous vitamin D₃ becomes restricted due to lifestyle (exclusively living indoors or wearing concealing garments while outdoors) and geographic relocation (migration from high annual UV radiation to low annual UV radiation) (Bacharach et al. 1979).

Also, the finding that moderately to deeply pigmented humans require from two to six times as much UVB radiation as lightly pigmented humans require for catalyzing the synthesis of an equivalent amount of previtamin D₃ makes deeply pigmented individuals more susceptible to vitamin D₃ deficiencies, especially when living in regions exposed to low levels of UVB. This finding demonstrates how certain degrees of skin pigmentation of an individual are better adapted for living in different regions of the world.

The significant advantage that certain skin pigmentations have in different parts of the world have suggested that when the early *Homo* migrated from eastern Africa to the Mediterranean/European region, significant loss in pigmentation occurred. This was likely due to the lower UVB exposure that the early *Homo* felt in the northern region and resulted in natural selection of lighter pigmented individuals that were better adapted to

the low UVB environment. The decrease in melanin production in the body was done for the necessary synthesis of vitamin D₃ (Whitehead et al. 1981). The depigmentation is likely to have been further aggravated as the early *Homo* continued migrating farther north (Jablonski 2012). With the comparison of figures 3 and 4, one can further see the relationship of latitude with skin pigmentation. From the comparison of figures 3 and 4, one notices that in regions that are exposed to significant amounts of UV are regions that have populations with darker skin pigmentation while in regions that are exposed to less UV, their skin is lighter (Figure 3; Figure 4).

The females examined in the above reflectometry study returned a higher value for skin reflectance, which meant that they are consistently lighter than males under equal environmental setting. This finding on the sexual differences in skin reflectance also conforms to the previous observations, which also stated that females are consistently lighter than males (Robins 1991). These findings further support, from an evolutionary perspective, that females needed lighter skin pigmentation to permit relatively greater UV light penetration to integument for previtamin D₃ synthesis to meet their requirement of extra calcium during the courses of pregnancy and lactation (Whitehead et al. 1981). Such demands for increased previtamin D₃ synthesis are met by increasing plasma concentrations of 1,25-dihydroxyvitamin D, which ultimately enhances calcium absorption in the intestine (Whitehead et al. 1981); (Holick 2007). Therefore, skin pigmentation in females demonstrates an intricate compromise between the necessity of photoprotection and previtamin D₃ synthesis (Jablonski and Chaplin 2000). This finding now enables researchers to nullify the hypothesis that human skin coloration was partly determined by sexual selection.

Current findings on the evolution of human skin pigmentation showcase the significant effects of cultural practices on rates of change in skin pigmentation among human populations. Factors such as migration (especially in the last 20,000 years) and social customs are identified as the major drivers behind such variances. For example, the first modern human inhabitants of Tibet were clad, not naked and that practice is reflected in the lighter skins of the Tibetans, which, going by the annual average UVMED of that region, should have been a shade darker (Jablonski and Chaplin 2000) (Figure 7). Accordingly, their face remains lightly pigmented to allow for adequate previtamin D₃ synthesis (since the rest of their body is typically covered) (Jablonski 2012). Adaptations to skin pigmentation due to migration is seen when immigrants to the New World, who were native to tropical regions, progressively developed lighter skin pigmentation (Holick et al. 1981).

Conclusions

The reasoning and evidence cited above lend support to the idea that variations in skin color are adaptive and that they are related to the regulation of UVR penetration in the integument. However, the above findings also facilitates the emergence of two points: first, the review shows that the evolution of human skin pigmentation remains dynamic due to the dynamism of the factors influencing it. These factors include UVR, state of lifestyle, and intricate mechanism of the human body; second, the findings show that the importance of maintaining harmony between two conflicting factors, such as requirement of vitamin D synthesis and protection from harmful impact of UVR has been triggering evolution of human skin pigmentation.

The significance of external influence on the human body and the coupling of two contrasting needs for its survival together highlight the fact that humans require certain natural preconditions for existence, and it is the degree of deviation from these preconditions that ultimately causes them to evolve. This in turn points to the fact that if the degree of deviation goes beyond manageable means of the evolution mechanism for some reason, the survival of humans will be at stake. From this perspective, there are many reasons be concerned in this regard:

Manmade disasters that damage the environment such as deforestation, dam-building (the water that accumulates as a result of dams also results in the accumulation of sediment and decaying matter; as water levels decrease, sun makes more contact with the decaying matter and results in the production of methane from the water), use of fossil fuels, nuclear reactor emissions, poor waste management, inefficient recycling system recycling, and emission of chlorofluorocarbon (CFC) due to increased use of air conditioners all significantly contribute to the rise in UVR. This causes one to wonder how far the evolutionary mechanism in humans will evolve in skin pigmentation level (or in other aspects for that matter) to cope with such environmental changes.

Also, the increasing trend of indoor living due to integration of digital technology in daily life and a constant flow of new gadgets of comfort are preventing humans from exploiting UVR the rate of endogenous vitamin D₃ synthesis during exposure to UVB, or it would narrow the relationship of vitamin D with bone-building, lactation, and the diseases due to vitamin D deficiency.

Changes in dietary pattern as well as changes in dietary intake due to lifestyle changes are telling of the current state of humans, where they are increasingly getting

accustomed to working indoors for the greater part of the day and going outside at night. This causes one to wonder how our bodies will adapt to such changes in the future: will humans begin relying more on dietary supplements for their vitamin D₃ or will the body adapt and begin storing increasing amounts of the vitamin during UV exposure.

The above queries leave one wondering – will it be possible for the human evolutionary mechanism to adapt to the growing changes?

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Appendix

Table 1. von Luschan's (1927) chromatic scale

| | | | | | | | |
|--|---|----|--|--|----|----|--|
| | 1 | 10 | | | 19 | 28 | |
| | 2 | 11 | | | 20 | 29 | |
| | 3 | 12 | | | 21 | 30 | |
| | 4 | 13 | | | 22 | 31 | |
| | 5 | 14 | | | 23 | 32 | |
| | 6 | 15 | | | 24 | 33 | |
| | 7 | 16 | | | 25 | 34 | |
| | 8 | 17 | | | 26 | 35 | |
| | 9 | 18 | | | 27 | 36 | |

Table 2: Fitzpatrick Scale

| Type | Also Called | Sunburning | Tanning Behavior | Von Luschan's Chromatic Scale |
|------------|------------------------------|------------------|----------------------------|-------------------------------|
| I | Light, pale white | Often | Occasionally | 1–5 |
| II | White, fair | Usually | Sometimes | 6-10 |
| III | Medium, white to light brown | Rarely | Usually | 11-15 |
| IV | Olive, moderate brown | Rarely | Often | 16-21 |
| V | Brown, dark brown | Very rarely | Sometimes darkens | 22-28 |
| VI | Very dark brown to black | Extremely rarely | Naturally black-brown skin | 29-36 |

| Skin type (human population) | Time of exposure to maximize pre D ₃ formation (h) (range and mean) | Multiplier for amount of time relative to skin Type IIIa, calculated from mean time of exposure | Estimated annual average UVMED necessary to catalyze pre D ₃ formation |
|------------------------------------|---|---|---|
| Type IIIa (European) | 0.50–0.75 (0.625) | 1 | 68.1 |
| Type V (Asian) | 0.75–1.50 (1.125) | 1.8 | 122.6 |
| Type VI (African American) | 3.00–3.50 (3.25) | 5.2 | 354 |

Table 3. Data on the time of exposure necessary for maximal previtamin D₃ production in three different skin types. (Jablonski and Chaplin 2000)

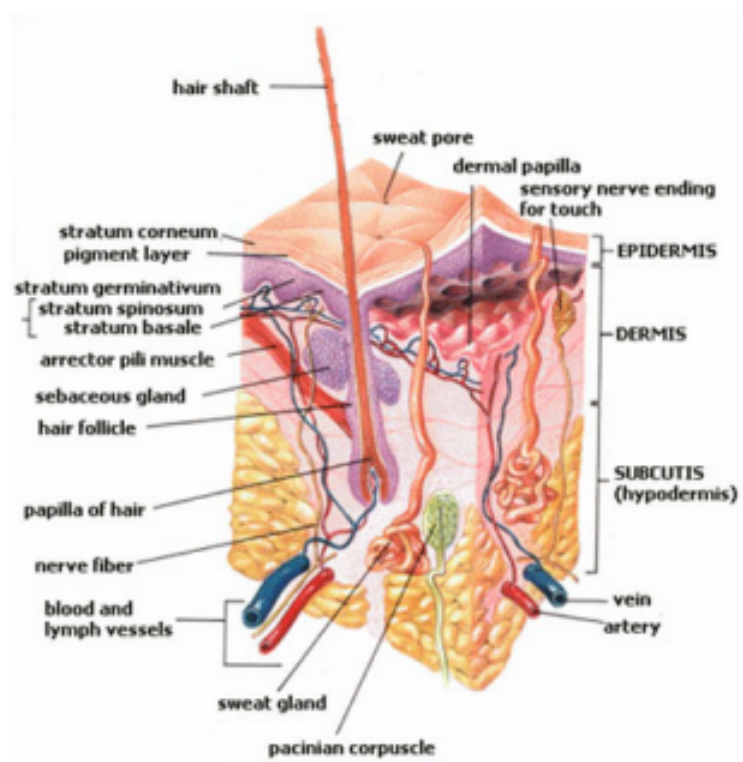


Figure 1. The anatomy of the skin (Mayo Clinic 2012)

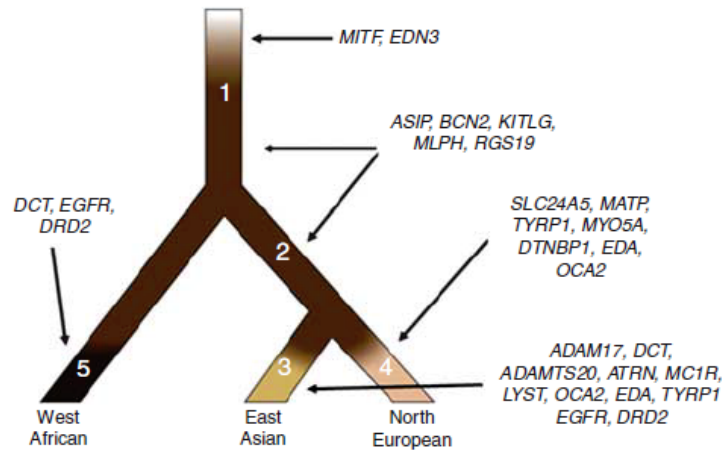


Figure 2: The evolutionary genetic architecture of skin pigmentation in three populations (Quillen and Shriver 2011). The above figure shows that although gene flow occurred among human populations, selection on genes involving skin pigmentation varied most greatly in populations that migrated from Africa (where man is believed to originate). The genes listed have demonstrated signatures of selection as (1) shared among all humans, (2) shared between East Asian and European populations, (3) unique to East Asian populations, (4) unique to European populations, and (5) unique to West African populations (Quillen and Shriver 2011).

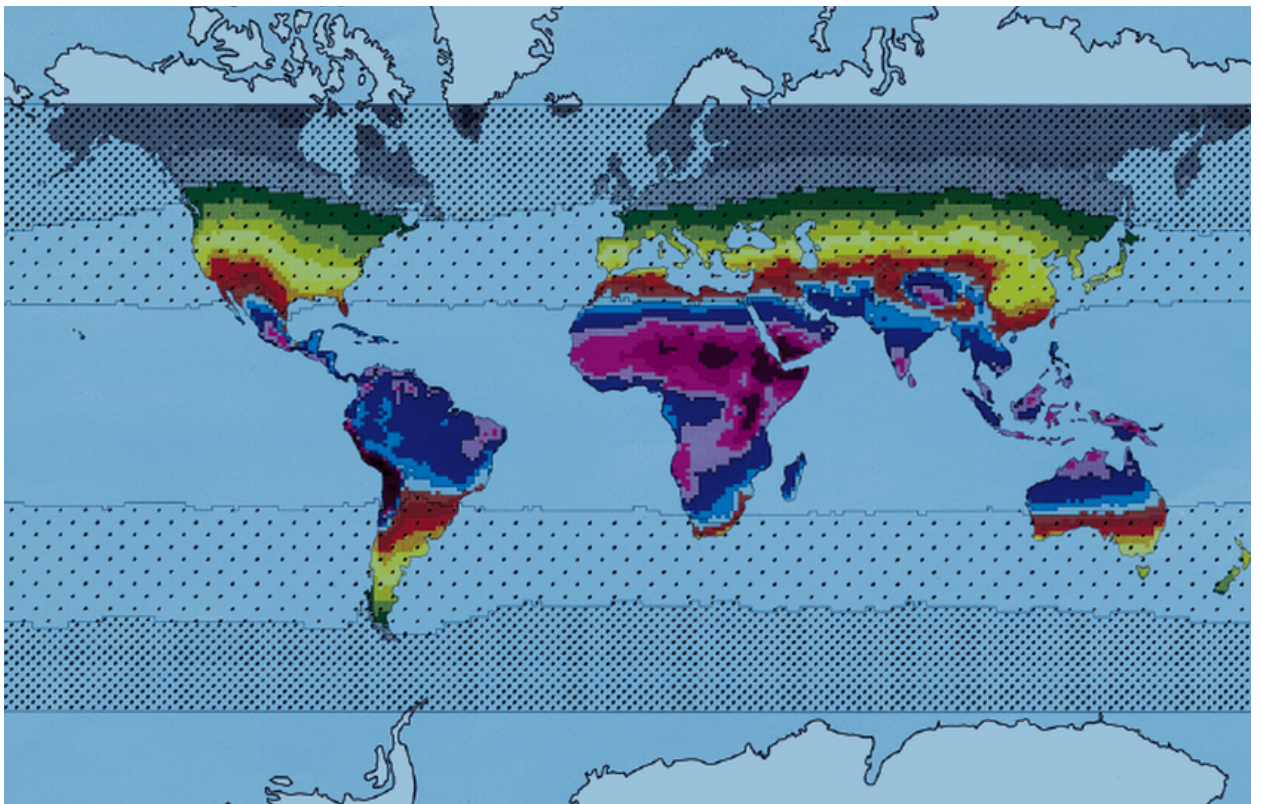


Figure 3. Three Global Zones with their different potentials for UV-induced vitamin D₃ synthesis (Jablonski 2000). The highest annual values for UVMED are shown in light violet, with incrementally lower values in dark violet, then in light to dark shades of blue, orange, green and gray (64 classes). The color white denotes areas for which no UVMED data exist. In the tropics, the zone of adequate UV radiation throughout the year (Zone 1) is the middle region in which there are no dots. The lightly dotted area indicates Zone 2, in which there is not sufficient UV radiation during at least one month of the year to produce previtamin D₃ in human skin. Zone 3, in which there is not sufficient UV radiation for previtamin D₃ synthesis on average for the whole year, is indicated by numerous dots.

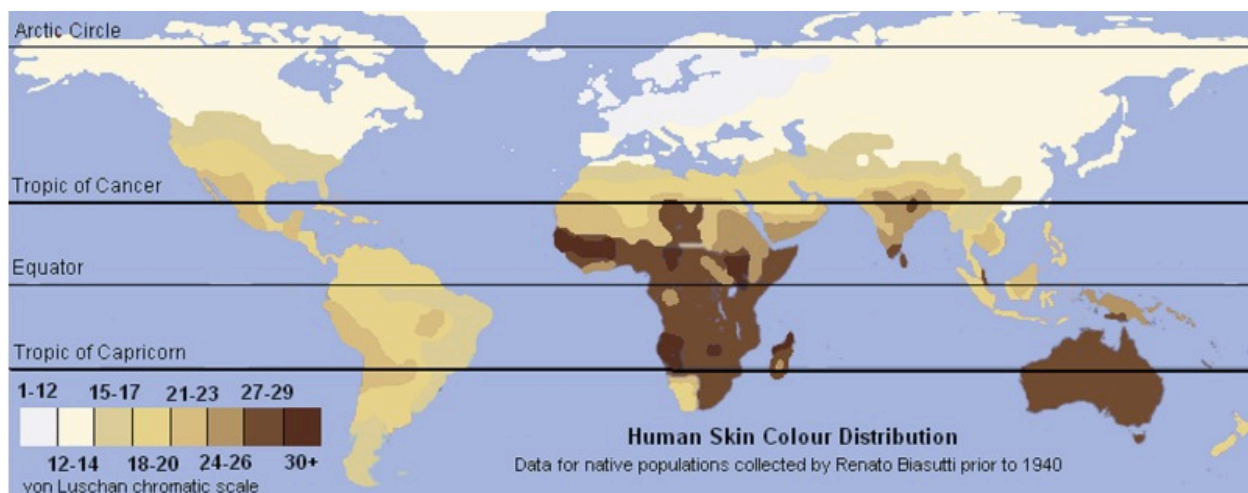


Figure 4. Map of the distribution of skin color throughout the world based on the von Luschan scale. Higher numbers on the von Luschan scale indicates darker skin color. (O'Neil 2012)

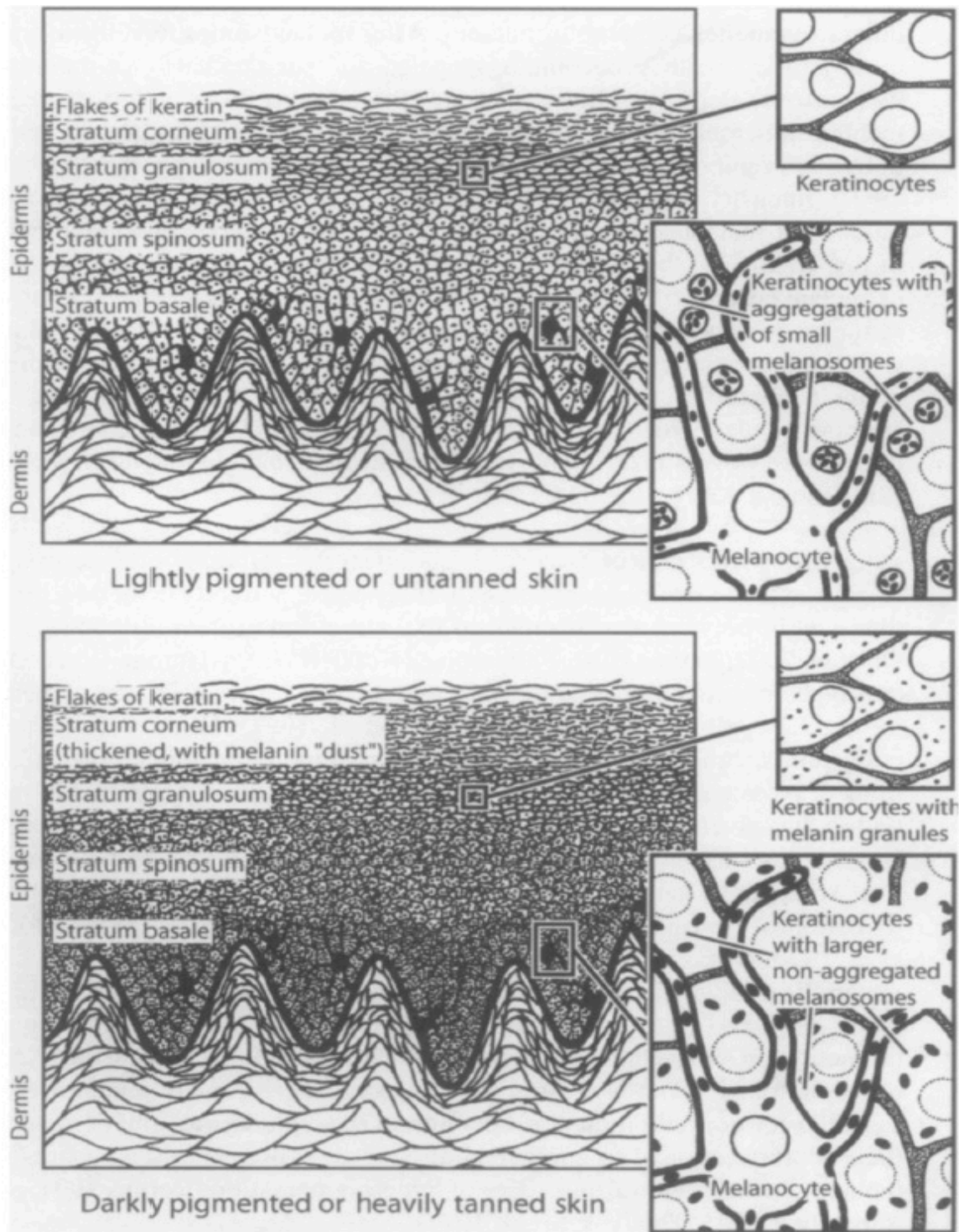


Figure 5 (Jablonski 2004). Depictions of cross-sections of lightly and darkly pigmented skin (Jablonski 2004). This figure shows the differences that exist in the stratum corneum as well as the distribution of melanin.

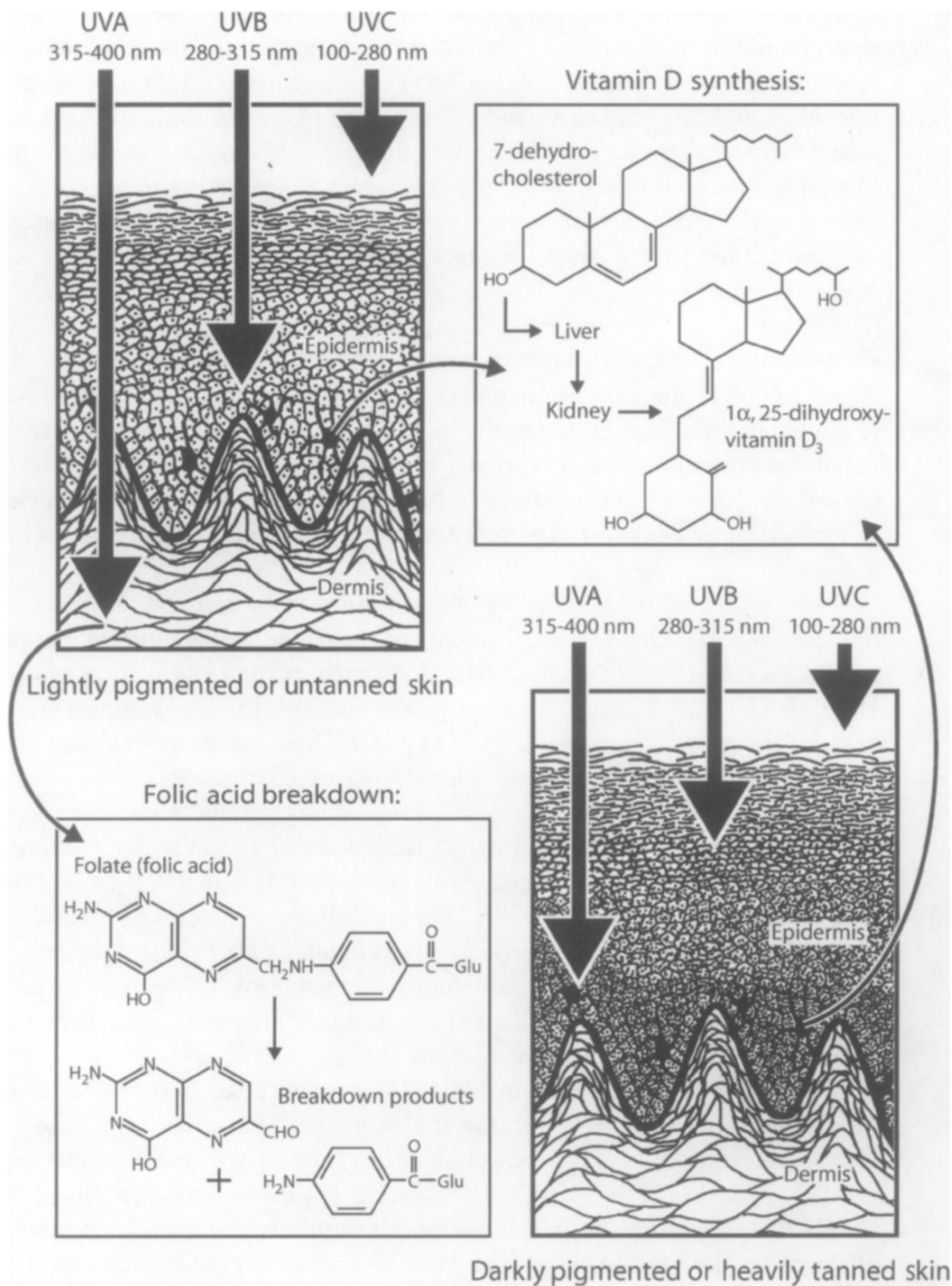


Figure 6 (Jablonski 2004). Depiction of light and darkly pigmented skin and how the absorption of different UV rays differ. This figure also depicts the folic acid breakdown, which is necessary for many human developmental processes as well as the synthesis of Vitamin D.

In evolutionary time:



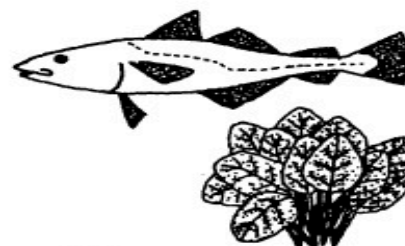
Environment:
 - UV radiation levels
 - Precipitation



Migration:
 - Length of migration
 - Recency of migration



Other cultural adaptations to climate:
 - Clothes wearing
 - Shade seeking
 - Shelter
 - Timing of daily activities



Diet:
 - Vitamin D content
 - Folate content

During a human lifetime:

Environmental influences:

- UV radiation exposure
- Application of tanning or bleaching agents



Endogenous influences:

- Genetic, esp. MC1R locus
- Age

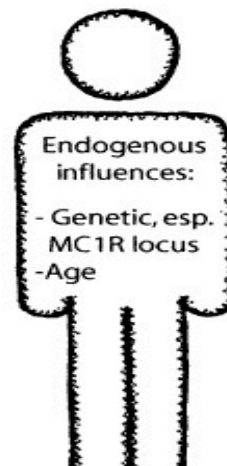


Figure 7 (Jablonski 2004). A summary of the influences on human skin pigmentation in evolutionary time as well as during the human lifetime.

Curriculum Vitae

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