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Review Article

Ethnic skin types: are there differences in skin structure and function?[1]

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Synopsis

People of skin of colour comprise the majority of the world's population and Asian subjects comprise more than half of the total population of the earth. Even so, the literature on the characteristics of the subjects with skin of colour is limited. Several groups over the past decades have attempted to decipher the underlying differences in skin structure and function in different ethnic skin types. However, most of these studies have been of small scale and in some studies interindividual differences in skin quality overwhelm any racial differences. There has been a recent call for more studies to address genetic together with phenotypic differences among different racial groups and in this respect several large-scale studies have been conducted recently. The most obvious ethnic skin difference relates to skin colour which is dominated by the presence of melanin. The photoprotection derived from this polymer influences the rate of the skin aging changes between the different racial groups. However, all racial groups are eventually subjected to the photoaging process. Generally Caucasians have an earlier onset and greater skin wrinkling and sagging signs than other skin types and in general increased pigmentary problems are seen in skin of colour although one large study reported that East Asians living in the U.S.A. had the least pigment spots. Induction of a hyperpigmentary response is thought to be through signaling by the protease-activated receptor-2 which together with its activating protease is increased in the epidermis of subjects with skin of colour. Changes in skin biophysical properties with age demonstrate that the more darkly pigmented subjects retaining younger skin properties compared with the more lightly pigmented groups. However, despite having a more compact stratum corneum (SC) there are conflicting reports on barrier function in these subjects. Nevertheless, upon a chemical or mechanical challenge the SC barrier function is reported to be stronger in subjects with darker skin despite having the reported lowest ceramide levels. One has to remember that barrier function relates to the total architecture of the SC and not just its lipid levels. Asian skin is reported to possess a similar basal transepidermal water loss (TEWL) to Caucasian skin and similar ceramide levels but upon mechanical challenge it has the weakest barrier function. Differences in intercellular cohesion are obviously apparent. In contrast reduced SC natural moisturizing factor levels have been reported compared with Caucasian and African American skin. These differences will contribute to differences in desquamation but few data are available. One recent study has shown reduced epidermal Cathepsin L2 levels in darker skin types which if also occurs in the SC could contribute to the known skin ashing problems these subjects

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experience. In very general terms as the desquamatory enzymes are extruded with the lamellar granules subjects with lowered SC lipid levels are expected to have lowered desquamatory enzyme levels. Increased pores size, sebum secretion and skin surface microflora occur in Negroid subjects. Equally increased mast cell granule size occurs in these subjects. The frequency of skin sensitivity is quite similar across different racial groups but the stimuli for its induction shows subtle differences. Nevertheless, several studies indicate that Asian skin maybe more sensitive to exogenous chemicals probably due to a thinner SC and higher eccrine gland density. In conclusion, we know more of the biophysical and somatosensory characteristics of ethnic skin types but clearly, there is still more to learn and especially about the inherent underlying biological differences in ethnic skin types.

Résumé

Les gens qui ont une peau de couleur représentent la majorité de la population mondiale et les sujets asiatiques en représentent plus de la moitié. Pourtant la littérature consacrée aux caractéristiques de ces sujets est limitée. Plusieurs groupes de travail ont essayé au cours des dernières années de comprendre les différences sous-jacentes de la structure et de la fonction de la peau de différentes ethnies. Maisla plupart de ces études ont été réalisées à petite échelle et dans certains cas les différences observées entre les individus au niveau de la qualité de la peau ne font pas ressortir de différence entre races. Récemment, un besoin d'études reliant les diffèrences génétiques et phénotypiques entre différents groupes raciaux s'est fait sentir et de ce fait beaucoup d'études à grande èchelle ont été entreprises. La différence la plus évidente, entre les peaux ethniques, est leur couleur liée à la présence de la mélanine. La photoprotection induite par ce polymère influence le taux de vieillissement de la peau entre les différents groupes raciaux qui finalement sont tous sujets au processus de photovieillissement. Généralement, les caucasiens ont des signes plus précoces et plus importants de formation de rides et de relâchement de la peau; en général, les problèmes d'augmentation de la pigmentation sont observés sur les peaux de couleur, bien qu'une grande étude ait rapporté que des sujets originaires de l'Asie de l'Est vivant aux U.S.A. avaient le moins de taches pigmentaires. On pense que la réponse d'une induction hyperpigmentaire est due à un signal envoyé par le récepteur 2 activé par une protéase. Le récepteur 2 augmente en même temps que la protéase activatrice dans l'épiderme des sujets ayant une peau de couleur. Les changements dans les propriètés biophysiques de la peau en fonction de l'âge montrent que les sujets qui ont la pigmentation la plus sombre gardent une peau plus jeune par comparaison aux groupes qui possèdent une pigmentation moins forte. Toutefois, bien qu'ayant un stratum corneum plus compact, il existe des rapports divergents sur la fonction barrière de ces sujets. Dans le cas d'agression chimique ou mécanique, la fonction barrière du stratum corneum est considérée plus forte chez les sujets à peau plus foncée, malgré leurs taux plus faibles encéramide. On doit garder à l'esprit que la fonction barrière du stratum corneum dépend de toute son architecture et pas seulement de sa teneur en lipides. On considère que la peau asiatique à unePIE (TEWL) basale similaire à la peau caucasienne, ainsi que des taux en céramides comparables, mais on constate que dans le cas d'agression mécanique, elle possède un effet barrière le plus faible. Des différences dans la cohésion intercellulaire sont évidentes. A contrario, on a mis en évidence des taux d'hydratation (NMF) plus faibles dans son stratum corneum, comparativement à la peau caucasienne et afro-américaine. Ces différences expliquent les variations au niveau de la desquamation, mais on a très peu de données sur ce sujet. Une étude récente a mis en évidence des taux réduits de Cathepsin L2 dans l'épiderme des types de peau plus sombre, ce qui, si cela se produisait dans le stratum corneum, expliquerait les problèmes biens connus de cendrage de la peau que ces sujets connaissent. En terme très gènéral, étant donné que les enzymes liées à la desquamation sont libérées avec les granules lamellaires, on s'attend à ce que les sujets ayant des taux de lipides faibles dans le stratum corneum aient des taux d'enzymes liés à la desquamation faibles. On constate chez les sujets noirs une augmentation de la taille des pores, de la sécrétion du sébum et de la microflore cutanée. On observe également chez ces sujets une augmentation de la taille des granules mastocellulaires. Le phénomène de peau sensible se retrouve à une fréquence similaire dans les différents groupes raciaux, mais il existe des différences subtiles dans lesstimuli nécessaires pour l'induire. En tout cas, plusieurs études montrent que la peau

asiatique est peut-être plus sensible aux produits chimiques exogènes, ce qui probablement est dû à un stratum corneum plus mince et à une densité de glandes eccrines plus élevées. En conclusion, c'est sur les caractéristiques biophysiques et somatosensorielles des différents types de peaux ethniques que nous en savons plus, mais il est clair qu'il nous reste à comprendre encore beaucoup de choses principalement sur leurs différences biologiques.

Introduction

Despite the fact that the vast majority of subjects on earth are subjects with skin of colour, there is very little, and often contradictory, information on their differences in skin structure and function apart from the inherent skin coloration differences and sensitivity to irradiation.

There are subtle differences in the definitions of 'ethnic' and 'race'; however, these are usually used interchangeably in the literature. In reality though, 'ethnic' usually defines broader groups of populations with common culture and/or language (i.e. Mongoloid). 'Race', on the contrary, defines one specific population in terms of genetic similarities (e.g. Japanese). According to its definition, a race is classified genetically. In this way five groupings of races has been proposed:

1 Caucasoid: Europeans, people of the Middle East and India.
2 Negroid: African Negroes, African Americans, African Caribbeans.
3 Mongoloid: East Asiatics, Indonesians, Polynesians, Micronesians, Amerindians, Eskimos.
4 Australoid: Aborigines, Melanesians, Papuans, Tribal Folk of India, Negritos.
5 Capoid: Kung San tribe of Africa.

Obviously, new races can form, e.g. the American Negro is now considered racially distinct from the African Negro [1].

Another common classification system is the skin phototype (SPT). SPT has been used to categorize all people including those with pigmented skin based on the skin reactivity to UV irradiation. It correlates the colour of the skin with its dynamic ability to respond to UV light with burning or tanning reactions (phototypes I–VI) [2]. A classification system specific for Japanese skin has also been developed [3].

However, of the ethnic skin differences that are reported to exist, the biophysical and biochemical differences are not clearly delineated due to contradictory data between studies. For most studies, two to three ethnic groups were investigated and in some cases, very small numbers of subjects participated in the studies except for the most recent publications. In many studies, the racial backgrounds of the subjects were also not fully characterized, i.e. subjects were classified as Black, White or Asian.

As a result of testing on different body sites, anatomical site differences in skin functionality are responsible for the greater contradictory evidence between studies, e.g. between testing the volar forearm and the face. Studies are sometimes also not directly comparative due to the different geographical locations of where the study was conducted. Even within one country there can also be dramatic geographical differences in climate which will influence the structure and function of the skin as it adapts to that particular climate. Seasonal changes in skin composition also occur as reported by Rogers *et al.* [4] and stratum corneum (SC) barrier function and desquamatory properties acclimatize to different environments as reported by DeClercq *et al.* [5]. Blood circulating hormones also influence skin status, e.g. monthly changes in circulating sex hormones in women, and stress can induce changes in the levels of circulating stress hormones, e.g. cortisol which can affect skin structure and function in both short and long term. This has recently been exemplified by Choi *et al.* [6]. Circadian rhythms also occur that influence, in particular, sweat and sebum secretions [7, 8]. Naturally diet will have a big influence on skin composition and function [9]. Nevertheless, this review will summarize the differences that are reported in the literature.

Differences in skin coloration

Pigmentation is the most obvious difference in skin characteristics between different racial groups [1]. This racial variation is dependent on the quantity of melanin, amount of UV exposure, genetics, melanosome content and type of pigments found in the skin. Four chromophores are responsible for the varying colors found in human skin: hemoglobin, oxyhemoglobin, melanin and carotenoids. Hemoglobin and oxyhemoglobin contribute to the pinkish colour in Caucasian skin by absorption of specific wavelengths of light and allowing red to be reflected back. The various brown shades seen in black and sun-tanned skin are a result of

melanin. Carotenes are the source of yellow-orange pigmentation. Other hues are caused by a combination of all the pigments.

Melanin is a natural skin pigment which protects the skin from UV damage. It is synthesized in melanocytes and packaged into melanosomes that are found dispersed throughout the epidermis. Melanosomes are found most prominently in the basal layer of the epidermis and serve to protect germinating nuclei of epidermal cells from UV radiation damage. The packaging and arrangement of skin pigments are responsible for the differences in skin pigmentation which serve to protect an individual.

Melanin is a stable free radical comprising oxygen-centered semiquinone-type radicals in eumelanin and nitrogen-centered semiquinonimine free radicals in pheomelanin. The polymers act as a radiation sink, a redox buffer and a cation-binding material. The high degree of conjugation within the polymer permits the movement of electrons between quinine and catecholic residues so that the pigment can act as a single or two-electron free radical exchanger and thus as a free radical scavenger. The residual charges on hydroxyl and carbonyl groups enable melanin to act as a cation trap for toxic metals. The combination of carbonyl functions and a high degree of conjugation renders melanin a powerful radiation absorbent material with a quasi-monotonic photon absorption spectrum that extends from UV into the infrared range [10].

Eumelanin and pheomelanin are both derived from the common substrate tyrosine. The hydroxylation of tyrosine to dihydroxyphenylalanine (DOPA) and the oxidation of DOPA to dopaquinone are both reactions catalyzed by the tyrosinase enzyme [11].

Compared to tyrosinase, other enzymes involved in the human melanin synthesis pathway including tyrosinase-related protein-1 (TRP-1) and tyrosinase-related protein-2 (TRP-2) are relatively poorly understood. In the mouse, TRP-1 is a dihyproxyindole carboxylic acid (DHICA) oxidase and TRP-2 is a DOPAchrome tautomerase. Unlike tyrosinase, TRP-1 and TRP-2 apparently do not bind to copper but iron has been shown to bind TRP-1 whereas zinc is required at the active site of TRP-2. In pheomelanin production, cysteinyldopas are synthesized by the addition of cysteine to dopaquinone which are then oxidized to form the mature polymer. Once formed, both dihyproxyindole (DHI) and DHICA are further oxidized to their respective indole quinines prior to polymerization to form eumelanins. It is believed that tyrosinase can act as a DHI oxidase and TRP-1 as a DHICA oxidase. Another protein called pmel17 may also be a DHICA polymerase. In humans, TRP-1 does not have any DHICA oxidase activity.

During the process of melanogenesis orthoquinones are generated which have a great propensity to react with and covalently attach to protein and nucleic acids. As a result melanogenesis is restricted to specialized organelles – melanosomes [12]. The reaction of the intermediate quinines and melanosomal proteins results in a regular pattern of deposition on a matrix and inactivation of tyrosinase and other enzymes by the time the organelles are fully melanized and transferred to keratinocytes as granules. Melanosomes have been found to be more numerous in American and African Blacks and Australian aborigines. Melanosomes in these ethnic groups are also larger and individually dispersed compared with those found in other racial groups. Melanosomes were found grouped together in complexes of two or more in European-American Caucasians, East Indians, Japanese, Chinese and Mongoloids. Variations in melanosome arrangement, together with the quantity and type of melanin present, are responsible for the differences in skin pigmentation [1].

The final eumelanin polymers formed from DHI are generally dark brown or black and are largely insoluble whereas the polymers formed from DHICA are light brown in colour and are alkali soluble. There are likely to be mixed polymers *in vivo* but when each monomer is in excess it dictates the characteristics of the final polymers. So melanin can be considered to be made up of three distinct components:

1 light colored yellow or red alkali soluble pheomelanin;
2 light brown alkali soluble DHICA-enriched eumelanin;
3 dark brown or black insoluble DHI-enriched eumelanin.

In skin types V and VI, DHI-eumelanin is the largest single component (60–70%), followed by DHICA-eumelanin (25–35%) with pheomelanin being a relatively minor component (2–8%). Moreover, there is a comparative enrichment of DHI-eumelanin at photoexposed sites. There is also a highly significant correlation between the concentrations of spherical melanosomes and pheomelanin [13]. Examining other racial types Alaluf *et al.*

[14, 15] demonstrated that the most lightly pigmented types (European, Chinese and Mexican) have approximately half as much epidermal melanin as the most darkly pigmented skin types (African and Indian). However, the composition of the lighter skin types was comparatively more enriched with lightly colored alkali soluble melanin components (3×). Regardless of the ethnicity epidermal melanin content is significantly greater in photodamaged forearm skin compared with sun-protected skin but there is only a modest enrichment of lightly colored alkali soluble melanin (1.3×). The proportion of spherical melanosomes was low in all skin types (<10%) suggesting that pheomelanin in only a minor component even of the lightest skin types. Analysis of melanosome size revealed a significant variability with ethnicity: African having the largest, followed by Indians, Mexican, Chinese and European (but these did not include skin type I). There was a strong trend towards enrichment of spherical melanosomes at photoprotected sites in all ethnic groups except the Chinese. These results would suggest that the pheomelanin pathway in human skin is saturated quite quickly. However, it is also reported that in chronically exposed skin there is a stable two-fold increase in melanocytes numbers compared with protected skin. This would explain the two-fold increase in the melanin content of photoexposed skin without a substantial effect on melanin composition.

Primary stage I and II melanosomes are seen in lightly pigmented skin whereas stage IV melanosomes are seen in darkly pigmented skin types. The smaller melanosomes of lightly pigmented skin are clustered in groups of 2–10 within secondary lysosomes and are degraded in the spinosum layers. In darker skin types melanosomes are larger and singly dispersed and degraded more slowly such that melanin granules can still be found in the stratum corneum [15].

Differences in racial skin pigmentation may also be due to differences in the production of melanin. *In vitro* cultures of black melanocytes produce higher levels of melanin when compared to melanocytes of white skin. However, it has been found the number of tyrosinase molecules in black and white skins are nearly equal. Nevertheless, TYRP-1 levels are also reported to be elevated in darkly pigmented skin compared with Mexican, Caucasian and European skin types [16]. This indicates that there may be structural differences in the melanogenic enzymes between the two racial groups or that the enzymes may be under tighter metabolic control in different melanocytes. Differences in the structure of melanosomes in different ethnic skin types may also contribute to differences in tyrosinase activity. Increased stratum corneum melanin dust can also be found with increasing skin pigmentation [17].

The number of melanocytes decreases with aging. Despite this, focal localized hyperpigmentation is a feature that accompanies photoaging. It is visible as uneven pigmentary patches, and is especially common among members of the Mongoloid race.

Intracellular pH may also influence melanogenesis and differences in different ethnic skin cells have been studied. In human pigment cell lysates it has been [18, 19] demonstrated that melanin synthesis was maximal at pH 6.8. Equally, neutralization of intramelanocyte pHs using vATPase proton pump inhibitors also showed rapid increases in melanogenesis, a preferential increase in eumelanin production and maturation of melanosomes. The pink locus protein (P protein), which normally mediates neutralization of melanosomal pH is a key facilitator in this process. Proton pump inhibitors only influenced melanogenesis in melanocytes from Caucasian epidermis and not from black skin indicating potential differences in melanocytes pH in these different racial groups. It would appear that the intracellular melanocytes pH is closer to neutral in subjects with type V/VI skin. Thus, Caucasian melanocytes appear to have reduced melanogenesis as a result of a decreased intracellular pH.

Melanosomes are transferred from the melanocytes to the keratinocytes, and phagocytosis has been suggested as a transfer mechanism. The protease-activated receptor-2 (PAR-2) is involved in this process and its levels have been shown to correlate with skin of colour [20]. This is a seven transmembrane G-protein-coupled receptor activated by cleavage of its extracellular domain by serine proteases such as trypsin or mast cell tryptase. This cleavage exposes a new N-terminus which then acts as a tethered ligand activating the receptor. PAR-2 is present on the keratinocytes, is UV inducible and its inhibition prevents UVB-induced skin tanning [21]. Hyperpigmented skin expresses PAR-2 at higher levels than lightly pigmented skin and PAR-2-induced phagocytosis is elevated in dark skin keratinocytes. Subjects with skin type I showed delayed upregulation of PAR-2 compared with skin types II and III.

Following UV insult, however, melanogenesis is a slow process. After a single UV dose and 7 days later the amount of melanin increase in subjects with black skin was 12%, in Asians 4% and in white skin about 1% [22]. It has been reported that in type III (French) skin nuclear melanin caps were absent from basal keratinocytes in subjects tanned during their vacation period [23]. This has recently also been demonstrated in Japanese subjects [24]. This would indicate that the initial stages of the tanning process come from a redistribution of already preformed melanin and/or transfer of already synthesized melanosomes to suprabasal keratinocytes. Nevertheless, all SPTs experience some degree of photodamage as measured by cyclobutane pyrimidine dimers (CPD), 6–4 photoproducts and p53 levels [22]. De Winter *et al.* [25] also demonstrated increased p53 immunoreactivity in the epidermis after a single UV exposure and the levels were higher in darker skinned individuals. Equally, Bonnet *et al.* [26] found increased p53 levels 24 h after one minimal erythemal dose (MED) in Chinese subjects and these levels were greater in sun-exposed skin compared with sun-protected areas. This tumor-suppressor gene is known to regulate cell cycle progression and up-regulates DNA repair enzymes following DNA damage thus allowing time for the repair of DNA. It also induces apoptosis of critically damaged cells. In lightly pigmented skin the removal of CPD is less efficient. Wagner *et al.* [27] reported that European Americans who had a low constitutive pigmentation had a significantly higher burn response and a lower tanning response than Hispanics and East Asians, i.e. they burn more and tan less than a person with higher pigmentation. In this respect Rijken *et al.* [28] recently compared the responses of black and white skin to solar-simulating radiation and except for some DNA damage in the suprabasal epidermis the subjects with skin of colour did not show any increase in neutrophils, active proteolytic enzymes and diffuse keratinocyte activation unlike the Caucasians. Thus, it would appear that Asian skin has other mechanisms than the presence of melanin to protect against UV irradiation. This could be dietary but possibly it is related to the induction of p53 and DNA repair enzymes.

The skin of Japanese subjects has also been categorized using four skin types [3 and CERIES Wesite]. Both the MED and the minimal melanogenic dose (MMD) increased from skin types I–IV and the MMD was found to be greater than the MED. This is completely different for the traditional SPT classification where skin types III and IV, the presumed Japanese skin type, the MMD was less than the MED. These studies suggest that erythema can precede melanogenesis in Japanese subjects whereas darker skinned Caucasian subjects stimulate a tanning reaction more easily. Camel *et al.* [29] using the individual typological angle (ITA) to classify skin types (lighter skin has ITA values 41–60° whereas darker skin types have ITA values 28–41°) found that lighter skinned Asians living in Singapore had ITA values similar to French Caucasian subjects (45.7 vs. 46.3) but the MED was significantly less (MED = 1.3 vs. 1.5). The darker skinned Asians (ITA = 34.6) had an MED of 1.6. These subjects had significantly greater melanin as measured with the mexameter.

Racial differences in stratum corneum structure

Number of stratum corneum corneocyte cell layers

On average, it has been found that stratum corneum from Negroid skin contained more corneocyte cell layers than that from Caucasian skin (mean 21.8 cell vs. mean 16.7 cell layers) [30]. Since no significant difference in thickness of the stratum corneum between the Whites and Negroes were found, the cell layers in Negroid skin were thought to be more compact perhaps reflecting greater intercellular cohesion. Consistent with this, Johnson *et al.* [31] found the mean electrical resistance of adult black skin to be twice that of adult white skin suggesting increased cohesiveness.

Comparing subjects with skin types V and VI to skin type II/III it has been demonstrated that the darkly pigmented subjects required more tape strippings to disrupt the epidermal barrier suggesting that the darker phenotype indeed had a greater number of cellular layers [32]. Conversely, Asian stratum corneum may be thinner as the number of tape strippings to increase TEWL were less [33].

Stratum corneum corneocyte size, phenotype and desquamation

Corcuff *et al.* [34] reported that there were no significant differences in corneocyte size between

Black, White and Asian subjects (911, 899 and 909 μm^2 respectively). However, the desquamation rate was higher in the black subjects: 26 500, 11 800, 10 400 corneocytes per cm^2, i.e. the spontaneous desquamation was increased by approximately 2.5 times in black subjects. Nevertheless, Warrier *et al.* [35] found the opposite with a greater desquamation index on the cheeks and forehead of Whites compared with blacks. Manuskiatti *et al.* [36] reported no differences in desquamation black and white women. This is a good example where body site variation needs to be considered as Roberts and Marks [37] has demonstrated large differences in desquamation on different body sites.

Analysis of corneocyte size, quality and phenotype is important as smaller cells usually correlate with epidermal hyperproliferation and a tendency to develop dry skin with corresponding changes in lipid levels. Per unit area there are more intercellular lipids present in tissue with smaller corneocytes. The stratum corneum undergoes a maturation process induced by the enzyme transglutaminase towards the surface of the skin. However, using Nile red and involucrin staining as an indicator of corneocyte maturation no differences in different racial groups have been identified. The face is heterogeneous in the type of corneocytes that are present, and increased immature cells are observed in dry skin of all ethnic groups [38].

Stratum corneum lipid content

The early studies of Rienertson and Wheatley [39] and Wiegand *et al.* [30] suggested that the lipid content of stratum corneum of black skin was higher than that of white skin. More recently Sugino *et al.* [40] reported TEWL and water content (WC) values with concentrations of sphingolipids and ceramides in the skin of Blacks, Whites, Asians and Hispanics. They found differences (significance unknown) in TEWL values among the four ethnic groups. In decreasing order the amount of ceramides was highest in: Asians > Hispanic > Caucasian > Black. The total levels of ceramides were approximately 50% lower in stratum corneum from Negroids compared with Caucasians and Hispanics (10.7 $\mu g\ mg^{-1}$ vs. 20.4 and 20 $\mu g\ mg^{-1}$ respectively). This corresponds to the lowest TEWL and the highest WC values for Asians and the opposite for Black subjects. However, the differences for TEWL are contradictory to the results of others, who found no significant differences in TEWL between Black, White and Hispanic subjects of northern California [41]. Meldrum *et al.* [42] found no differences in scalp SC lipid levels and ceramides between subjects in the U.K. and Thailand in the wet season but the levels of lipids were dramatically lowered if they had dandruff. In the dry season greater quantities of SC lipids were present in Thai subjects tending to confirm the results of Sugino *et al.* [40]. Hellemans *et al.* [33] reported similar SC ceramide levels for Asians and Caucasians, but African Americans had lower ceramide levels.

Stratum corneum barrier function

TEWL is the total amount of water vapor lost through the skin and appendages under non-sweating conditions. Most studies have demonstrated that Blacks have a greater TEWL than Whites but these have been on small numbers of subjects. For instance, Wilson *et al.* [43] reported that TEWL was 1.1× that of Caucasians and Kompaore *et al.* found significantly higher TEWL after tape stripping in Blacks and Asians. Others have reported the opposite on larger numbers of individuals, e.g. Berardesca *et al.* [41] reported no differences between subjects of Negroid, Caucasian and Hispanic descent. Sugino *et al.* [40] reported that TEWL was greater in the order: Blacks > Caucasians > Hispanic > Asian. Nevertheless, Estanisiao *et al.* [44] have reported a difference in TWEL of a factor of 2 between different Asian groups. In contrast, Aramaki *et al.* [45] found no differences in TEWL between Japanese and German women.

Using a tape stripping approach Reed *et al.* [32] found that darker skinned individuals required a greater number of tape strippings to elicit a doubling in TEWL compared with Whites. The black subjects also recovered faster by measuring the recovery back to baseline TEWL. In support of this Warrier *et al.* [35] reported that TEWL on Black subjects was less than TEWL on Caucasians on the cheeks and legs. However, Berardesca *et al.* [46] found that TEWL was 1.2× greater on Negroid subjects compared with Caucasian subjects after tape stripping the stratum corneum three and six times. Hellemans *et al.* [33] recently reported that the number of tape strippings of the SC required to reach a TEWL of 18 $g\ m^{-2}\ h^{-1}$

was higher in African Americans compared with Caucasians and was actually lower in Asians. This is consistent with a thicker stratum corneum for Negroids and a thinner stratum corneum for Asians. Berardesca *et al.* [41, 47], for instance, observed no racial differences in TEWL on either the volar or dorsal forearms.

Skin surface temperature differences can contribute to the differences in TEWL. However, Wilson *et al.* [43] measured TEWL *in vitro* for cadaver skin from subjects with black or white skin. In these controlled conditions black skin had a significantly higher mean TEWL compared with the skin from the white subjects.

Stratum corneum water content

Using resistance, capacitance, conductance or impedance techniques to measure SC water content gives conflicting results in different studies. Each study uses a different method, again only small numbers of subjects are studied and like other biophysical parameters contradictory results are found. Johnson *et al.* [31] reported lower water content in subjects with black skin compared with white skin; Berardesca *et al.* [46–48] found no difference between black and white subjects. Later, Berardesca *et al.* [41] reported increased water content on the volar forearm of Hispanic subjects which was decreased in Caucasian subjects. Negroids were intermediate in this measure. Sugino *et al.* [40] reported greater water content in Asians compared with Caucasians, Blacks and Hispanics whereas Warrier *et al.* [35] found greater water content on the cheeks of black subjects compared with white subjects. Manuskiatti *et al.* [36] reported no differences between Black and White subjects.

According to Hillebrand *et al.* [49] there is a general increase in capacitance readings with increasing age on the cheek and forearm. Between racial groups African Americans, Latinos and East Asians had significantly higher hydration than Caucasians. Warrier *et al.* [35] also reported lower capacitance values in Caucasians compared with African Americans.

In all these studies body site variation needs to be considered when comparing across studies as it has been recently reported that reduced NMF levels are found in facial skin compared with forearm skin [50]. However, Hellemans *et al.* [33] most recently reported than in subjects of Asian descent there were lowered SC NMF levels compared with Caucasians and African Americans.

Stratum corneum pH

Berardesca *et al.* [47] found no significant difference in skin surface pH values between Black and Caucasian women but that after tape stripping the skin the pH significantly decreased in the Negroid subjects after three tape strippings. No differences were observed in the deeper layers of the stratum corneum. Consistent with these results Warrier *et al.* [35] reported that the pH was lower on cheeks of Black subjects compared with Caucasians but no differences were observed on the face. Examining the pH of the cheek, forehead, arm and calf, Hillebrand *et al.* [49] did not find any trend in different racial groups with increasing age.

Skin surface microflora

Blacks subjects have been reported to have a greater density of propionibacterium acnes compared to white subjects but the values were not statistically significant [35]. Rebora *et al.* [51] have also shown increased aerobic bacteria (650% greater) and *Candida albicans* (150% greater) on black skin compared with white skin.

Racial differences in epidermal–dermal function

Racial differences in epidermal–dermal structure become especially pronounced during photoaging. Naturally, the darker the skin phenotype, the greater the skin protection against UV irradiation. White subjects exhibit numerous focal areas of atrophy and necrosis. Equally there is greater dermal damage in the lighter ethnic groups.

Racial differences in skin elasticity and viscoelasticity were determined on the dorsal and volar forearm using the Twistometer (Dermal Torque Meter equivalent) in African Americans, Hispanics and Caucasians was reported by Berardesca *et al.* [41]. Skin thickness was increased on the sun-exposed site in all racial groups. However, skin extensibility was the same on both sites for black subjects whereas both dorsal sites on Hispanic subjects and White subjects showed reduced extensibility. However, the elastic modulus was only increased on the dorsal skin of the Caucasians. Black subjects showed the same elastic recovery

on both sites whereas both Hispanic and White subjects showed reduced recovery and viscoelasticity on the dorsal forearm. These differences are probably due to the greater sun protection capability of black skin. Warrier *et al.* [35] found that the elastic recovery was 1.5 times greater in Black compared with White subjects on the cheeks with no differences on the legs.

Overall I would expect less signs of aging, i.e. maintenance of skin elasticity in darker skinned individuals [Negroids are reported to have an intrinsic sun protection factor (SPF) value of approximately 13].

Racial differences in cutaneous appendages

Eccrine, apocrine and apoeccrine sweat glands [52]

Several papers suggest that there are differences in the number of sweat glands between different racial groups. However, when measuring sweat gland functionality, acclimatization needs to be taken into consideration as this will influence the onset and type of sweating process. Thus there is probably a greater density of actively sweating glands in the tropics rather than real differences in gland numbers. Differences in electrolyte content may occur where Negroids do not resorb as much sodium chloride as Caucasians. Apart from this no other compositional differences are reported but they are highly likely to occur.

There are some very early studies in this area which indicate that Black subjects have larger apocrine glands and in greater numbers than Caucasians and Chinese. They can be as much as three times greater in Negroid subjects. There is also a greater proportion of secretion of apocrine fluid by black subjects; secretions were more turbid and had a different odor.

The apoeccrine gland is a somewhat forgotten gland which develops at puberty from the eccrine gland. It is present in the axilla, per-anal regions and on the face particularly in the nasal skin. Its fluid does contain some lipid but it is mainly water and electrolyte. However, it is a much bigger gland and is reported to secrete at 10× the rate of the eccrine gland. Again these are found in greater number in black vs. white facial skin. In the axilla these glands are reported to represent up to 45% of the glands present and they secrete fluid directly on the skin surface unlike apocrine glands.

Sebaceous glands

The sebaceous gland is attached to the hair follicle by a duct and it produces sebum, a mixture of squalene, cholesterol, cholesterol esters, wax esters and triglycerides that are secreted on to the skin surface. On route the triglycerides can be hydrolyzed to free fatty acids by bacterial lipases. Sebum should not be considered as a liquid but as a semi-solid. Various crystalline lipid domains are present and these will vary according to composition which may be due to racial or seasonal variations. For the latter there is less oleate in sebum in summer compared with winter for instance.

Comparing lipid in hair samples it has been shown that black subjects have 60–70% more lipid in their hair compared with white subjects. Black subjects also have bigger sebaceous glands which contribute to the increased sebum secretion. Consistent with these reports, studies from Hillebrand *et al.* [49] recently reported a greater pore count fraction in African Americans but the number of pores increases with age in all racial groups. The level of sebum secretion on the forehead was reported to increase during the early decades peaking in the 30–40s and then declines. African Americans showed significantly more sebum excretion than East Asians whereas Hispanics had the lowest.

There are few studies on sebum composition and the effect of race. One study examining Caucasians and Japanese found that like Caucasians, Japanese subjects have a greater predominance of straight chain fatty acids in their sebum wax esters than branched chain fatty acids [53], but the Japanese had a greater quantity of C16 iso-branched chain fatty acids. Japanese men also appear to have a greater sebaceous gland activity compared with Caucasians. Nevertheless sebum levels decline with age.

The incidence of acne is similar across different racial groups but acne responses appear to show differences between the different racial groups. In response to coal tar, Caucasians develop inflammatory lesions whereas subjects with Black skin open comedones develop. Thus, in subjects with white skin rupture of the follicles occurs but in Negroid subjects hyperproliferation and retention of horny cells occur [1].

Cutaneous irritation in different racial groups

Examining the effects of mustard gas in the early 1900s Marshall *et al.* [54] demonstrated that fewer black men (15%) developed erythematous reactions compared with white subjects (58.6%). In other studies Weigand *et al.* [55], using erythema as a measure, confirmed this against a variety of chemicals. However, the accuracy of this type of measure especially in black skin is questionable and more recent studies have used a variety of instrumental measurements.

Examining the effect of sodium lauryl sulphate (SLS) (0.5% and 2%) on untreated skin, ethyl acetate washed skin and skin pre-occluded with plastic for 30 min to hydrate the skin in Blacks, Whites and Hispanics demonstrated no differences in the untreated skin; all racial groups behaved equally to 2% SLS but significantly higher TEWL values were seen only with pre-occluded skin exposed to 0.5% SLS [1]. Hicks *et al.* [56] using *in vivo* reflectance confocal microscopy demonstrated that compared to subjects with black skin, subjects with white skin had a more severe clinical reaction to SLS. Increased TEWL and increased SC and epidermal swelling were apparent. Others evaluated skin irritation to 2% SLS by TEWL in fair skinned Chinese, darker skinned Malaysians and very dark Indians and found no differences at baseline or after the SLS treatment [1].

Microscopic evaluation of skin by Sueki *et al.* [57] has revealed that subjects with black skin contain larger mast cell granules compared with subjects with white skin. The granules were 1.5× larger and contained more parallel linear striations (PLS) and had 30% less curved lamellae. Typtase was located in the PLS regions in black skin compared with curved lamellae in white skin. These differences may account for the pruritis experienced by these two populations and the PAR system may be involved. This enzyme may also be responsible for activating PAR-2 leading to hyperpigmentation. Barrier compromised individuals have elevated epidermal serine proteases [58]. Equally, Rawlings and Matts [59] recently reviewed the importance of good barrier function in reducing inflammation and itching.

Somatosensory irritation may be different between the different racial groups.

Black subjects have a lower threshold to thermal temperature and heat compared with Caucasians [60]. Frosch and Kligman [61] originally reported that the most common 'stingers' were light complexioned persons of Celtic origin but Grove *et al.* [62] suggested that this was just related to a history of soap and cosmetic use. Clearly soap washing can disrupt the SC intercellular lipid lamellae as reported by Rawlings *et al.* [63]. Robinson [64] demonstrated population differences in acute skin irritation responses. Increased skin reactivity was noted for Asian subjects compared with Caucasian subjects to 100% octanoic acid, 20% SLS, 100% decanol and 10% acetic acid. Slight but distinct reductions in the time to respond to the chemicals were observed for the Asian subjects lending some support to the perception of increased reactivity in Asian vs. Caucasian subjects. In this respect, Arakami *et al.* [45] reported no differences in barrier function after an SLS challenge in Japanese and German subjects but Japanese were significantly more sensitive to a lactic acid stinging test on the face. Foy *et al.* [65] also reported that irritation responses were greater in Japanese women compared with Caucasian women. It is thought that the differences in sweat gland density may account for this [66] as it has been reported that there are no differences in nerve fiber density in different racial groups [67]. Conversely, Yosipovitch and Thang reported no differences in pain perception and skin sensitivity between Asian and Caucasian subjects. Nevertheless, one needs to consider the climatic conditions when these studies were conducted. In these tropical regions the stratum corneum barrier can be compromised in the wet seasons.

Jourdain *et al.* [68] examining self-perceived sensitive skin in different racial groups in the San Francisco area found no difference in perception of sensitive skin prevalence. However, Europeans had a higher skin reactivity to wind, Asians a greater reactivity to spicy food and sudden changes in the environment and tended to suffer more from itching more frequently, Hispanics had a lower reactivity to alcohol and African Americans were the least reactive.

Examining sensitive skin it has been presented that French subjects report a higher incidence of facial skin sensitivity than other racial groups (75% vs. 40–50%). Additionally four types of skin sensitivity were described with different responses in Caucasians and Japanese [CERIES Wesite]. A greater vascular response was seen in Japanese subjects and a greater outbreak of spots was asso-

ciated with the menstrual cycle in the French subjects although other studies have highlighted the occurrence of spots as being a problem in Asian racial groups. When asked about skin discomfort scaling, itching and redness were the most frequently described problems by French consumers. Itching and tightness were associated with cleansing, pollution and tiredness, reddening of the skin was associated with stress, emotions, diet/alcohol and changes in temperature whereas spots were associated with the menstrual cycle.

Ota *et al.* [69] also reported that 37–50% of women in Japan, South America and Asia had self-perceived sensitive skin. In Japanese population the presence of acne is also included in the perception of sensitive skin problems which occur to a greater extent in the summer months of the year. Greater skin itching and scaling was observed in the winter months of the year. Consistent with a micro-inflammatory state and epidermal hyperproliferation corneocyte sizes were reduced.

Racial differences in photoaging

Grimes *et al.* [70] also reported that the increased severity of problems in African American skin compared with Caucasian skin was hyperpigmentation and uneven skin tone. Griffiths *et al.* [71] and Larnier *et al.* [72] initially suggested that pigmentary changes occur with greater incidence than skin wrinkling in Asians compared with Caucasians. Skin wrinkling does, however, still occur. Tsukahara *et al.* [73] developed a photographic scale to assess human facial wrinkles. Using these scales they found that the correlation of facial wrinkling scores with advancing age was in the order: eye area > lower eyelid > upper eyelid > cheek > forehead > mouth area > nasolabial grooves > glabella.

Hillebrand *et al.* [74] also developed image analysis methods to discern the effects of photoaging on Japanese subjects living in northern (Kagoshima) and southern (Akita) Japan. The individuals living further north had a significantly greater number and larger facial wrinkles and hyperpigmented spots, more yellow skin, a rougher skin texture and reduced stratum corneum hydration. These subjects demonstrated on average an 'older skin age' of 8 and 16 yrs for facial wrinkles and hyperpigmentation respectively.

Interestingly body mass index was positively associated with hyperpigmentation in all racial groups except the East Asians. TEWL is normally elevated in obese subjects [75] and the inferior barrier possibly leading to enhanced secretion of serine proteases could contribute to activating the PAR-2 system and skin pigmentation problem.

Photoaging is common in East and Southeast Asians because of the geographical proximity to the equator. Chung *et al.* [76] studying Koreans of the ages 30–92 years reported that seborrheic keratosis was the major pigmentary lesion in men but in women it was hyperpigmented macules. The moderate to severe wrinkling associated with photodamage became apparent at about 50 years. Women tended to have more wrinkling. Koreans usually do not have wrinkles before 30 years of age and usually are not first seen until 50 years and older. Reduced numbers of dermal vessels was apparent. In African Americans photoaging appears primarily in lighter complexioned individuals and usually does not appear until the late fifth or sixth decade of life. There are no reported studies on Hispanics but photoaging is the third most common dermatological diagnosis accounting for approximately 17% of visits.

Estanisiao *et al.* [44] also reported on the characterization of Asian skin in a multicenter study. Changes in skin wrinkling and mottled hyperpigmentation occured with aging and that the hyperpigmentary problems occurred at an earlier age in this racial group. Skin elasticity decreased with age whereas collagen cross-links increased with age. The age of onset of these changes was increased in the subjects with an earlier start in use of cosmetics.

Most recently Tsukahara *et al.* [77] compared the appearance of photoaging in Caucasian and Japanese females living in Cincinnati and Tokyo. Wrinkle and facial sagging, scores were higher in the Caucasian women. However, the more comprehensive data is that of Hillebrand *et al.* [49] comparing different ethnic groups living in Los Angeles. Increased skin wrinkling was observed in the order: Caucasian > Hispanic > African American > East Asian. In these studies Asians had the least hyperpigmented spots. So it appears that Far East Asian subjects have mechanisms other than melanin photoprotection to reduce the negative effects of UV irradiation on skin.

Differences in facial muscle positioning, content and their movements may contribute to these differences and diet may also contribute. Eating fish oil can deliver up to a sun protection factor as

high as 5 [78]. Nevertheless, these differences in photoaging are most probably related to melanin content and composition. For instance, for epidermis derived from Negroid subjects a protection factor has been shown to be 13.4 compared with 3.4 for white epidermis, i.e. a mean UVB transmission of 5.7% for black skin compared with 29.4% for white skin [79]. Equally the UVA transmission is 17.5% compared with 55.5%. For future studies the precise skin coloration needs more robust documentation probably with ITA values as more lightly pigmented Japanese subjects appear to be more sensitive to UV irradiation compared with Caucasian subjects.

Conclusions

1 Skin pigmentation dictates many of the changes in skin associated with aging. Nerveless, all skin types experience photoaging changes but the more darkly pigmented subjects show the dermatological signs of aging at a more advanced age compared with more lightly pigmented subjects. More lightly pigmented Japanese skin, however, appears to be more sensitive than originally anticipated (MED decreased). Skin wrinkling and sagging is a predominant problem of lighter skin types whereas mottled hyperpigmentation and uneven skin tone is associated with the darker skin types. However, one large study observed less pigment spots in Asians compared with other skin types in the US. Precise skin coloration values need to be taken into consideration to understand this further. Nevertheless, activation of the protease receptor-2 is involved in skin hyperpigmentation and its activity correlates with SPT. Skin cosmetic use also needs to be carefully recorded as naturally the use of sun protection creams at an earlier age will help protect against photoaging. In general, however, subjects of Asian descent appear to have other mechanisms than melanin to protect against photoaging.

2 Differences in SC biology are apparent in different skin types. Asians in general have the lowest TEWL, highest water content and highest SC lipid levels. The findings are opposite for Negroid skin. Due to its enhanced spontaneous desquamation (and probably increased sebum levels) tape stripping revealed a weaker barrier when only using a few strips. However, on further tape stripping black skin apparently has a stronger barrier presumably due to its increased cohesiveness. This increased cohesivity may also explain the reduced potential to irritate black skin using a variety of chemical stimuli. Asian skin on the contrary is reported to be more sensitive to chemical stimuli presumably due to the higher sweat gland density or possibly due to a thinner SC where the number of tape strippings to break the barrier is reported to be less. Nevertheless, one recent report demonstrates reduced epidermal Cathepsin L2 levels in subjects of skin of colour (unpublished results courtesy of Miri Seiberg) which if also demonstrated in the SC may contribute to the reduced desquamation and increased prevalence of ashing found in these subjects.

3 Black skin has a greater gland pore size, increased apocrine and apoeccrine glands and greater sebum secretion. This probably accounts for the higher microbial flora present on black skin which is not compensated for by a slightly reduced stratum corneum pH.

4 Although considerable progress has been made in understanding the structure and function of the skin of different ethnic types, larger studies of the type reported by Hillebrand *et al.* [49] need to be conducted and skin colour type (ITA value) more carefully documented rather than using an ethnicity or racial label. Climatic and geographical locations need to be recorded as does use of cosmetics and precise timing of studies due to the known circadian and circannual variations that occur in skin function. The precise point in the female menstrual cycle will be also required as circulating hormones influence skin quality and in this respect even a psychological stress questionnaire should be acquired as stress hormones negatively affect the skin.

5 Aside from the biological understanding of the mechanisms of skin colouration and tremendous progress that has been made in understanding the signaling processes involved in hyperpigmentary responses of different racial groups (PAR-2 system), very little is understood of the biology of other skin structures in ethnic groups. Subjects with black skin have increased mast cells but decreased SC lipids. Differences in the levels of ceramides in Asian subjects are reported in different studies compared to the levels in Caucasian subjects but at least two studies report that their levels are greater than those found in Negroid skin. Ceramide levels are also reported to be greater in the SC of scalp skin in subjects

from Thailand compared with the U.K. Only one study has demonstrated differences in SC natural moisturizing factor levels where Asian subjects were reported to have lower levels compared with Caucasian and Negroid subjects.

Clearly, there is more to learn about the inherent underlying biological differences in ethnic skin types as well as their structural and biophysical differences.

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