Interdependence of Eye and Hair Colour, Skin Type and Skin Pigmentation in a Caucasian Population

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Eye colour, hair colour and skin colour are important risk factors for malignant melanoma and non-melanoma skin cancers. There are few studies in which the distribution of these pigmentation factors in risk populations has been assessed. The purpose of this study was to investigate the prevalence of the major eye and hair colours and the distribution of skin types and skin pigmentation in a Caucasian population. In 892 Danish Caucasians, eye colour, hair colour and skin type were assessed and facultative and constitutive skin pigmentation were measured objectively using skin reflectance spectroscopy. Blue eye colour and blond hair colour and skin type II were the most frequent (60%, 67% and 33% of subjects, respectively). All four major eye colours and four major hair colours (with the exception of red hair colour) were found within skin types I–IV and we could not predict the skin type or the constitutive skin pigmentation. Skin type could not be taken to classify individuals reliably according to their facultative or constitutive skin pigmentation. Key words: epidemiology; risk factor; skin reflectance.

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Persons of fair complexion, e.g. with blond or red hair and blue eyes and lightly pigmented skin, are clinically more prone to be sunburned and to develop sun-induced skin damage. In some phototest studies the phenotypic characteristics eye colour and hair colour have been found to be related to skin type and to minimal erythema dose (MED) (1–3). The incidence of skin cancer, cutaneous malignant melanoma (CMM), basal cell carcinoma (BCC) and squamous cell carcinoma (SCC), is increasing in white-skinned populations worldwide and skin cancer is now becoming a major health problem. The fair skinned Caucasians in Scandinavia are at considerable risk of skin cancer and the CMM incidence rates are higher in Scandinavians than in populations from southern Europe (4). It has been calculated that, given the current incidence rates, 1 in every 100 Danish males and 1 in every 80 Danish females will develop a CMM during their lifetime (5).

In analytic studies of skin cancer it has been found that the phenotypic traits eye colour and hair colour and skin type and skin colour are major risk factors for CMM (6, 7), BCC (8–10) and SCC (8, 9, 11). In a meta-analysis of 10 case-control studies of CMM with more than 3,000 cases and almost 4,000 controls the odds ratio (OR) for blue eyes compared to brown eyes was calculated to be 1.6 and for red hair colour and blond hair colour compared to black or brown colours the ORs were 2.4 and 1.8, respectively (6). In a multicentre study on BCC and SCC from southern Europe, involving 1,549 BCC cases, 228 SCC cases and 1,795 controls, pale eye colour compared to dark eye colour had an OR of 1.4 for BCC and 1.8 for SCC, and red hair colour compared to black hair colour held an OR of 2.4 for BCC and 18.0 for SCC (9). Univariate estimations of OR without adjusting for exposure may be to underestimate the OR in sun-sensitive persons because these individuals probably expose themselves less to the sun than more sun-resistant persons.

In most brown-skinned and black-skinned populations there is little variation in hair and eye colour, but in Caucasians a great diversity of hair and eye colours is seen in connection with various degrees of skin pigmentation. Despite eye colour and hair colour being well-defined risk factors for melanoma and non-melanoma skin cancers, and are readily observable characteristics, surprisingly few studies assess the distribution of these pigmentation traits in Caucasian risk populations and the association of these pigmentation traits to skin type and to skin pigmentation.

The purposes of the present study were (i) to establish the distribution of hair colour and eye colour and skin type and skin pigmentation in a Danish Caucasian population, which has a high risk for development of melanoma and non-melanoma skin cancers and (ii) to investigate whether eye colour and hair colour are true predictors of skin type and skin pigmentation.

SUBJECTS AND METHODS

The population sample consisted of patients and relatives attending the outpatient clinic of the Department of Orthopaedics at the National University Hospital in Copenhagen. This clinic was chosen because persons of all ages and from a wide geographic area, including urban and rural areas, attended the clinic and because we assumed that pigmentation traits such as eye and hair colour and skin type would be unrelated to clinic attendance. In the study period, February to April 1995, approximately 1,000 persons were approached randomly by one of two trained interviewers in the clinic’s waiting area and invited to participate in the study. We wanted the study to be a Danish population study and therefore excluded persons not holding Danish citizenship. Of those approached, approximately 10% declined to participate for various reasons. The study was approved by the local Ethics Committee and all participants gave informed consent before entering. Eight-hundred-and-ninety-two persons were included (518 females and 374 males), with a mean age of 37 years (SD = 18 years; range 0–85 years). Seven persons (0.8%) stated that they had previously had a skin cancer or might have had a skin cancer. Since such information is doubtful, and we could not verify this, they were not excluded.

Study design

Study subjects were interviewed in a special study room in accordance with a standardized questionnaire on age, area of living, use of artificial tanning devices, hair colour and skin type. Eye colour was assessed and skin pigmentation was measured objectively at UV-exposed sites and in

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Table 1. *Distribution of eye colour, hair colour and skin type*

<table>
<thead>
<tr>
<th>Pigmentary trait</th>
<th>Study sample</th>
<th>Subgroup</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males, %</td>
<td>Females, %</td>
</tr>
<tr>
<td>Eye colour&lt;sup&gt;A&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>64.4</td>
<td>56.0</td>
</tr>
<tr>
<td>Green</td>
<td>14.2</td>
<td>20.1</td>
</tr>
<tr>
<td>Grey</td>
<td>6.3</td>
<td>6.0</td>
</tr>
<tr>
<td>Brown</td>
<td>13.7</td>
<td>17.9</td>
</tr>
<tr>
<td>NA</td>
<td>1.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Hair colour&lt;sup&gt;B&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>3.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Blond</td>
<td>68.0</td>
<td>66.8</td>
</tr>
<tr>
<td>Brown</td>
<td>23.8</td>
<td>27.5</td>
</tr>
<tr>
<td>Black</td>
<td>4.6</td>
<td>1.8</td>
</tr>
<tr>
<td>NA</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Skin type&lt;sup&gt;C&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>21.0</td>
<td>24.7</td>
</tr>
<tr>
<td>II</td>
<td>32.8</td>
<td>33.9</td>
</tr>
<tr>
<td>III</td>
<td>19.0</td>
<td>15.8</td>
</tr>
<tr>
<td>IV</td>
<td>26.3</td>
<td>22.8</td>
</tr>
<tr>
<td>V</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>NA</td>
<td>0.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

A subgroup of 414 persons, with an age and gender distribution as in the Danish population, was constructed from the total sample of 892 persons. <sup>A</sup>Eye colour assessed in study persons older than 1 year of age (study sample: n = 868; subgroup: n = 398). <sup>B</sup>Hair colour at 25 years of age (study sample: n = 667; subgroup: n = 287). <sup>C</sup>Skin type in persons older than 5 years of age; in children indicated by their parents (study sample: n = 856; subgroup: n = 390). M = males; F = females; NA = not available.

UV-shielded buttock skin. At the end of the examination study persons were given general advice on the risk known to be associated with excessive sun exposure and on sun protection. The interview and the pigmentation measurements took approximately 20 min for each person. The standardized questionnaire was pretested prior to the study, and during the study the two interviewers at regular intervals overheard each other’s interview to ensure that interviews were being performed consistently during the study period. Before starting the study and at regular intervals during the study the two interviewers performed simultaneous assessments of eye colour in the same study persons to ensure that eye colour assessment was uniform.

Eye and hair colour

Study persons were asked to indicate their natural (un-dyed) hair colour at 25 years of age in accordance with a 5-point scale: red, light blond, dark blond, brown or black. Eye colour (colour of the iris) was assessed by the interviewers on a 4-point scale: blue, green, grey or brown. We did not assess eye colour in infants younger than one year of age because we considered eye colour to be too unstable before this age.

Skin type

The skin phototype of the participants (anamnestic recall of burning tendency and tanning ability) was estimated using the Fitzpatrick classification (12) based on a person’s memory of their reaction to 2 h of sun on a sunny day at noon at the beginning of the summer period. This exposure in Denmark (situated at 56° latitude N) corresponds to a UV dose of 9 SED (one SED = 100 J/m²/298 nm, CIE erythema action spectrum (13)). The following six skin types were available; skin type I: always burn, never tan; skin type II: usually burn, tan less than average; skin type III: sometimes mild burn, tan about average; skin type IV: rarely burn, tan more than average; skin type V: brown-skinned persons, and skin type VI: black-skinned persons. In children, the skin type was indicated by their parents but we did not estimate skin type in persons younger than 6 years because we consider anamnestic skin typing to be too uncertain or impossible before this age.

Skin pigmentation

To objectively measure the skin pigmentation we used a portable skin reflectance spectroscopy (PBI UV-Optimize, Model 550/660, PBI Medical, Ringsted, Denmark) which utilizes wavebands of visible light at 555 and 660 nm to independently measure the skin pigmentation (the melanin content) and the skin redness (the haemoglobin content) and gives the results on continuous scales from 0 to 100% (14). Zero percent pigmentation corresponds to skin with no pigmentation at all, as in an extremely white person; 100% pigmentation corresponds to no light reflected back, as in theoretical absolutely black skin. The resolution of the pigmentation scale and precision of the instrument allows for at least 40 steps for measurements of skin pigmentation in European Caucasians (15). The measuring probe is held lightly against the skin and after a few seconds the readings, which are the average of three independent measurements, are given on the display. Before each measurement session the apparatus was calibrated on a white reference tile. Pigmentation measurements were performed at UV-exposed sites: on the forehead; on the upper chest in the infraclavicular region; on the upper back in the suprascapular region; at the lateral aspect of the upper arm 7 cm above the lateral epicondyle; at the medial aspect of the upper arm 7 cm above the medial epicondyle, and at the UV-shielded site of the medial and upper quadrant of the buttocks. The study period of February to April was carefully selected because the effect of seasonal variation on facultative skin pigmentation is least during these months of the year (16).

Statistics

The distribution of age and gender in the study sample was compared using the Chi-squared test to the expected distribution calculated from the Danish population as recorded by January 1996 (17). Analysis of eye colour, hair colour and skin type by gender was performed using the Chi-squared test, and skin pigmentation by gender was analysed using the unpaired t-test. Skin pigmentation according to skin types was analysed using the Mann-Whitney test. We considered p values less than 0.05 to be significant.

RESULTS

Study sample versus the Danish population

As expected, the majority of study persons came from the Copenhagen area, with 48% from the central part of Copenhagen (Copenhagen municipality; population January 1996: 476,751 persons (17)), but all of the 14 Danish counties were represented in the study sample. The observed age and sex distribution of the study sample was compared with the expected age and sex distribution calculated from the Danish population distribution in 1995 and was found to be different (p < 0.01) due to too few persons older than 59 years (approximately 50% of the expected number) and too many women in the age group 20–59 years (approximately 160% of the expected number). From the total sample of 892 persons a subgroup of 414 persons was selected (204 males and 210 females) with a similar age and sex distribution as in the Danish population by random reduction of persons in overrepresented age/gender groups. In this subgroup the distribution of eye and hair colour and skin type was also extracted (Table I). Compared to the total sample, only minor differences were found for the distri-
Eye colour

The dominating eye colour in the sample was blue with the fair eye colours (blue, green and grey) constituting the majority in both males and females; only 16% had brown eye colour (Table I). There was a gender difference with more males having blue eye colour and more females having brown eye colour ($p = 0.03$). All four eye colours were found in skin types I–IV (Fig. 1) and even brown eye colour was found in 13% of persons with skin type I. There was no obvious trend for any eye colour to be associated with a particular skin type. When eye colour was compared to objective measurements of constitutive skin pigmentation at the buttocks we also found all four eye colours within the four groups of pigmentation (Fig. 2), but with a slight tendency for brown eye colour to be more associated with darker pigmented skin. Eye colour was therefore found to be an unreliable predictor of anamnestic skin type and of constitutive skin pigmentation.

Hair colour

Only 4% of the sample of Caucasians had red hair colour at the age of 25 years and only 3% had black hair colour (Table I), with blonds (light blond and dark blond) being the dominating colours and with no statistical gender difference ($p = 0.15$). All hair colours were found in the four skin types I–IV except red hair, which was only found in skin types I and II (Fig. 1). There was a tendency for brown and black hair colour to be associated with the more sun-resistant skin types III and IV and with a higher degree of constitutive skin pigmentation (Fig. 2), while blond and red hair were more associated with the sun-sensitive skin types I and II and to lesser levels of constitutive pigmentation. However, these were only weak trends and overall hair colour was not found to be a predictor of skin type or of the degree of constitutive skin pigmentation.

Skin type and skin pigmentation

Skin type II was the dominant skin type found in 33% of the study persons (Table I), but a surprising 24% indicated skin type IV. There was no gender difference in the distribution of skin types ($p = 0.41$). Facultative skin pigmentation at UV-exposed sites was higher in females than in males except for the forehead (Table II). Buttock skin pigmentation was also statistically higher in females, but when solarium users were excluded there was no significant difference between constitutive skin pigmentation at the buttocks in either females or males (13.3 vs. 12.8, $p = 0.18$). More females than males were solarium users (33% of females and 14% of males). Considering only persons that were not solarium users, females still had sig-

### Table II. Skin pigmentation at various body sites

<table>
<thead>
<tr>
<th>Body site</th>
<th>Males</th>
<th>Females</th>
<th>M+F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>$p$</td>
</tr>
<tr>
<td>Upper arm, lateral</td>
<td>23.9</td>
<td>5.4</td>
<td>0.02</td>
</tr>
<tr>
<td>Chest</td>
<td>19.9</td>
<td>5.9</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Back</td>
<td>19.8</td>
<td>5.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Upper arm, medial</td>
<td>18.9</td>
<td>4.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Forehead</td>
<td>18.1</td>
<td>5.4</td>
<td>0.39</td>
</tr>
<tr>
<td>ButtockA</td>
<td>13.3</td>
<td>5.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>ButtockB</td>
<td>12.8</td>
<td>4.8</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Skin pigmentation measured by skin reflectance spectroscopy at UV-exposed skin sites in all persons (facultative pigmentation) and at buttock skin in all persons ($n = 889$) and in buttock skin of persons not using artificial tanning devices ($n = 666$). Only in persons not using artificial tanning devices can the buttock pigmentation be considered to be the constitutive pigmentation. Statistical analyses of gender differences by the unpaired $t$-test.

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skin colour scales which at best have a resolution of seven steps in Caucasians (15). Furthermore, we have previously established that measurements of skin pigmentation by reflectance spectroscopy in non-UV-exposed buttock skin will predict the UV sensitivity, as determined by a MED phototest, with a high degree of precision (18).

Anamnestic skin type is per definition dependent on the recall precision of the study person’s memory and cannot be objectively estimated. Furthermore, skin typing involves the combination of two different questions: burning susceptibility and tanning ability. This is unfortunate from a scientific point of view with only four possible combinations of burning tendency and tanning ability and may force Caucasians into choosing a wrong skin type because the right combination of burning tendency and tanning ability is not available (19).

Moreover, the questions used in skin typing may be interpreted differently in different populations and cultures. Despite this obvious weakness, skin typing has found widespread use in clinical and epidemiological studies because it is quick and easy and can be performed without any equipment.

We found that the major eye colour in the Danish population was blue, which compares well with the study of Pålsson et al. (20). Females had darker eye colours than males, which has also been found in other studies (21). Eye colour is not static, however, and in a longitudinal study in children from 3 months to 6 years of age Matheney & Dolan (21) have found an age trend with a decrease in the lighter eye colours and a corresponding increase in the darker colours with age. In parallel with age-associated changes in eye colour it has been shown that the hair of Caucasians tends to darken with age (22). We chose to look at hair colour at the age of 25 years to avoid this age-related trend because our study sample had a wide age range from 0 to 85 years.

In a study in 809 indoor office workers by M. Berg performed in four Swedish cities (23), it was found that the most frequent skin type was type III, with 61% of the study persons; the least represented was skin type I, with only 2%. The greatest variation in skin types between the four cities in the Swedish study was in skin type IV, with 4% of the study persons in Gothenburg in the south region of Sweden and 16% in Sundsvall in the northern region (23). In the German skin cancer screening campaign “Give Skin Cancer No Chance” (24) it was found that approximately 84% of the 24,432 screened persons were of skin type II or III.

We found that eye and hair colours were evenly distributed within almost all skin types and Hoffman et al. (24) found a comparable distribution of hair and eye colours within the four Caucasian skin types. Eye and hair colour cannot therefore be used as a substitute for skin typing in studies of sun sensitivity. However, eye and hair colour seem to carry additional information about sun reactivity which is not contained in the Fitzpatrick classification. These two pigmentary traits have been shown to be independent risk factors of skin cancer after adjustment for skin type (6, 9) and should therefore be included in analytic studies of skin cancer aetiology.

Our objective measurements of facultative and constitutive skin pigmentation in all skin types showed a considerable darkening of the skin at UV-exposed sites compared to non-UV-exposed buttock skin. Females had more pigmented skin at the exposed sites (Table II) but not at UV-unexposed buttock skin, suggesting that females had been more UV-exposed than males. The four major eye and hair colours were found within

**DISCUSSION**

In this study, we have used simple but clinically relevant colour scales to assess eye colour and hair colour rather than elaborate artificial scales which are of doubtful clinical relevance. For assessing skin pigmentation we benefited from having skin reflectance spectroscopy equipment giving objective pigmentation measurements on a continuous scale rather than artificial

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there seems to be an association between the two melanine types in hair and skin (31, 32).

Fig. 3, which correlates skin types to skin pigmentation, demonstrates clearly that Fitzpatrick skin types in Caucasians cannot reliably be used to classify individual subjects according to their constitutive skin pigmentation, since persons with a broad range of constitutive pigmentation are found within each skin type and there is wide overlapping between adjacent skin types. This is in accordance with our previous results on UV sensitivity in 248 persons of skin types I–V (15) and other phototest studies (19, 33). We have even found that reproducibility of anamnestic skin type is quite unsatisfactory because one of every three persons could not classify themselves in the same skin type 6 to 12 months after first being questioned (15). These observations stress the need for a new skin type classification system.

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