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Variation of human hairiness: a possible adaptation to solar radiation and melanin

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Abstract: Many theories have been advanced to explain human hairlessness, however, there is no consensus. This study of 76 males observed that skin reflectance measuring skin colouration and melanin pigmentation correlated with hair size and follicle density. Individuals with a greater concentration of melanin within the superficial layer of the skin had a lower follicle density and smaller sizes of hairs. In contrast, individuals with a lower melanin concentration and lighter skin colour had a full range of hairiness. This leads to the suggestion that over the course of human evolution, high concentrations of melanin in consistently exposed to ultraviolet radiation areas developed first and that hair loss was a consequence of competition in the skin between melanin production and hair growth. Darker pigmented skin and lower follicle density are significantly correlated ($R^2=0.283$; $p<0.05$). Individuals with darker skin had a mean of 4.91 follicles per cm2 whereas those with lighter skin reflectance had 11.20 follicles per cm2. This suggests that increased concentrations of melanin in the basal layer of the epidermis may limit hairiness by negatively influencing the skin's ability to produce hair.

Key words: evolution of hair, Von Luschan's Scale, skin colour reflectance, hairiness

Introduction

To date there is no accepted theory of mammalian hair growth (Foote, 2013). Humans appear considerably less hairy than chimpanzees and other primates, however, there is no clear explanation for this variation. Humans and chimpanzees have the same number of hair follicles and as a result, human hair must have become shorter and thinner (Morgan 1982). There are a number of theories and anecdotal evidence for the amount of hair varying across geographic groups of people. Thus, there is a need to quantitate variation in order to explain why differences occurred amongst individuals and geographical populations.

Theories contributing to the evolution of hairlessness:

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There are a number of theories which have been developed to aid in the understanding of human hairlessness. The aquatic ape theory suggests that Homo evolved to its erect, bipedal and hairless state by living in water (Hardy 1960). A newer version of Hardy's theory is the "wading hypothesis", which contends that ancestral humans had a peri-aquatic lifestyle (spending a substantial amount of time wading in shallow waters) which influenced hairlessness (Niemitz 2010). To the contrary, another theory states that human ancestors ventured onto dry savannah where they needed to thermoregulate more vigorously; both to lose heat gained by physical exertion, and collect heat in cooler periods, which would have been facilitated by loss of hair and exposure of naked skin to the environment (Rantala 2007). Similarly, the thermoregulatory theory is related to environmental conditions where naked skin proved advantageous. For survival Homo needed to hunt, and as a result evolutionary adaptations occurred to radiate heat produced during physical effort (O'Keefe et al. 2011). Extensive hunting in hot environments would have caused thermal stress on the body which demanded efficient temperature regulation by cooling (Pagel 2003). The parasitic theory is another plausible explanation for human hairlessness, related to when clothing was introduced, along with denser populations, which together were ideal conditions for ectoparasites (Rantala 1999). These ectoparasites would feed on skin (epidermis) which may have caused a reduction in body hair, as hair provides a protective environment for parasites to attach to and lay their eggs on (Dean and Silva-Jothy 2012). It still remains unclear which theory is more plausible. No matter which theory is correct, all humans have no hair cover dense or great enough to provide effective protection against environmental temperature. Human body hair, however individually variable, is vestigial. Thus there is no reason why the amount of hair on the human body should correlate with climatic conditions.

Human body hair may have evolved to become shorter and thinner, due to climatic conditions. There are two forms of hair on the body vellus and terminal. Vellus hair is much shorter, finer and inconspicuous, found in areas which appear naked yet there is hair, such as behind the ear (Dean and Silva-Jothy 2012). Whereas, terminal hair is thicker and more visible as it is found in areas including the legs, axilla, and arms (Toll et al. 2004). Thus, it is not necessarily a reduction of hair follicles for our seeming naked appearance but rather weaker hair. There is anecdotal variation among different groups and this study aims to study geographical variation in relation to other skin adaptations.

Skin Colour and Melanogenesis

Skin colour varies in all individuals, due to genetic variations, and it can be modified by exposure to ultraviolet (UV) radiation (Candille et al. 2012). Skin colour can vary during puberty (Sitek et al. 2012) and due to psychological stress (Sitek et al. 2012). In humans melanin occurs in the stratum basale layer of the epidermis of skin, whereas chimpanzees store their melanin deeper in the dermis (Becker 1927). Melanin produces the striking polymorphic variation in skin, hair and eye colour of humans (Candille et al. 2012). Hair pigment derives from melanin being taken up by keratinocytes (Hofreiter and Schöneberg 2010). Mel-

anocytes are specialised dendritic cells (Yuen and Jablonski 2010) that produce melanin in specialised cytoplasmic organelles, melanosomes (Jody et al. 2009). Melanosomes vary in size and degree of aggregation according to an individual's skin type and pigmentation (Jablonski 2004). Located within melanosomes is tyrosine, the regulatory amino acid of melanin, which is highly involved in melanin synthesis reactions (Lin 2007). There are two types of melanin, eumelanin (brownish-black) and pheomelanin (reddish-yellow); increased concentrations of eumelanin characterise darker tanned skin while concentrations of pheomelanin vary in each individual (Costin and Hearing 2007). However, pheomelanin is commonly present in individuals of red-haired Europeans, East Asians and Native Americans (Lessin et al. 2012). Primates have highly variable skin pigmentation, by having bluish, white, pink and black pigment in different areas of the body (Montagna 1972). Melanin protects the skin against excessive amounts of Ultraviolet B (UVB) radiation, therefore an accumulation of melanin is a reflection of geographic differences in people exposed to higher amounts of UV, and those whose ancestors were exposed to greater UVB radiation have a genetic tendency to produce more melanin (Robins 2009). Those individuals exposed to lesser quantities of UV will have lower amounts of melanin, and therefore lighter skin pigmentation (Sturm 2009).

It is possible that a reduced follicle density in individuals with greater concentrations of melanin, could be a result of melanin competing with follicular growth. Levels of tyrosine may differ in melanosomes which may also compete with the production of other structural elements of human skin such as hair follicles (Slominski et al.1991). There is some indication that hair density and growth are correlated depending on hair pigmentation (Van Neste and Tobin 2004). Therefore, it can be hypothesised that accumulation of high levels of melanin in the skin reduces follicle function, growth in numbers and size of hair. In females, due to cyclic changes in their physiology there is additional regulation of skin physiology and turnover of pigmentation, whereas in males the situation is simpler (Ali and Wojnarowska 2011).

Therefore, it is important to study a relationship between skin pigmentation, hair density and hair size in relation to geographic areas where people have originated in order to understand the causes of the variation in the degree of hairlessness. The aim of this work is to investigate correlations between skin colour, hair follicle density and size in relation to geographic origin in a sample of males from different continents.

Materials and Methods

There were two parts of this study: 1. Histology of skin and hair from different areas of the body, and 2. Correlation between skin pigmentation and hairlessness.

Histological study was conducted to ascertain variation of hair density and size across the different locations of the human body, in order to choose one area to represent human hairiness for a large sample.

Skin samples were obtained from four cadavers (two male and two female) donated to the University of Adelaide Medical School. Skin samples of 1 cm^2 to the depth of deep fascia were

dissected from the following locations (Fig. 1):

- Chin, anterior lower border of mental protuberance
- Back, midline centre of neck
- Chest, point where median sagittal plane is intersected by the plane running through the nipples. In females, the breasts were moved to anatomical position, before determining the plane running through the nipples.
- Axilla, apex of the dome of skin on the floor of the axilla, skin was taken from both axillae.
- Forearm, distal 1/3 of both dorsal forearms.
- Pubis, taken from the midline, mons pubis adjacent to the anterior commissure of labia majora in females, and midline just above the root of the penis in males.
- Medial leg, mid-point along the medial border of the shin between the upper border of the medial tibial condyle and apex of medial malleolus; from both legs.
- Skin samples were then processed for standard histology, stained with haematoxylin and eosin. Skin sections were cut parallel to the skin surface. Hair follicle density (number of follicles per cm^2) and the diameter of hair follicles and hair (i.e hair shaft), was measured on these samples. Skin measurements were taken using Nikon Bright Field Microscope with the use of NIS Basic Research Anatomy Software (2011), at 4 and 20 times magnification.

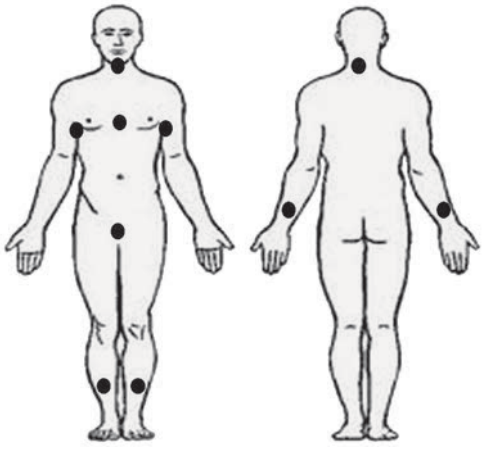

Fig. 1. Outlined human body with location of dissections

Hair follicle density, measured by counting the number of hair follicles within a 30,000,000 μm^2 at 4 times magnification. The part follicles falling along the left and anterior borders were not counted. To avoid bias four square shaped areas were selected that fell at the four corners of the section; 4 fields per slide.

Hair follicle diameter was measured by the longest and shortest diameter from epithelial sheath to epithelial sheath of each follicle at 20 times magnification.

Hair shaft diameter was also measured at the longest and shortest diameter from glassy membrane to glassy membrane of the hair shaft at 20 times magnification. Measurements were taken only from the hair follicles where hair was within the follicle.

Hair density, sizes and skin colour estimation:

Ethics approval was obtained from the University of Adelaide's Human Research Ethics Committee (HS-2013-017) to use live human male volunteers. Power analysis indicated that a sample size of 35 would be statistically sufficient. Males (n=76) aged 18 to 60 years from several geographic origins gave their consent to participate in this study. Females were excluded due to physiological changes. Information in relation to age, country of

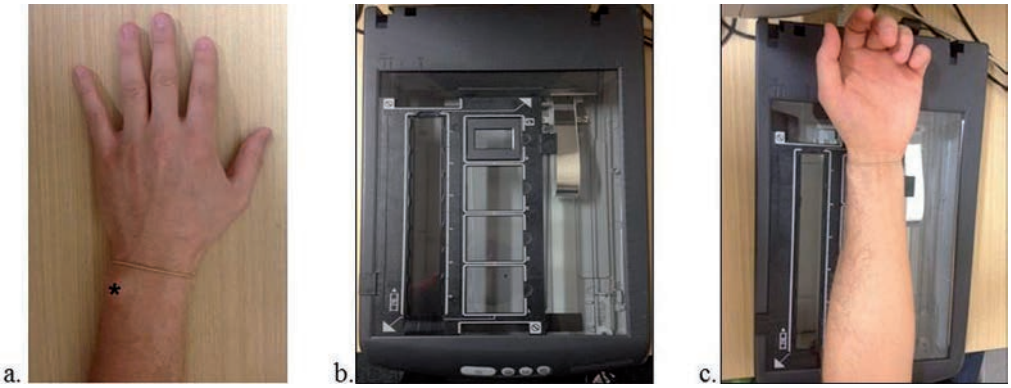

Fig. 2. A wrist of participant with elastic band above *radial styloid process b EPSON Scanner 2400 with 35 mm slide holder to ensure same area was measured by positioning the elastic band below the anterior white line of the box shown c Forearm supinated on scanner

birth of biological mother and father to determine geographic origin and recent tanning of the skin (in order to perform most accurate skin colour analysis), were obtained using a questionnaire.

In each participant an elastic band was placed around the left wrist just above the radial styloid process (Fig. 2a). The forearm was placed in a supinated position on top of a 35 mm slide holder (the elastic in line with the slide holder) on an EPSON Perfection Scanner 2400 (Fig. 2b), and scanned a 8.05 cm^2 area (standard window size of a slide holder) of the forearm; just proximal to the forearm band (Fig. 2c). This ensured the same skin area was used for measurements of skin with and without hair. Each scanned image was taken with the use of Adobe Photoshop (2010).

The image with forearm hair present was used to determine follicle density. The hair being present in this image made it easier to identify follicles of which a count was done (Fig. 3 A1 and B1). The part follicles which fell on the left and anterior side were not included. The participant was then asked to shave the region outlined by the researcher using a disposable safety razor in a single stroke, to ensure that full length of hairs was shaved from the skin surface. The shaved hair was collected and ten hairs from each participant were used for analysis of length and width. All measurements were taken using NIS Basic Research Anatomy Software. The shaved area of the forearm was scanned again and the image was used for the determination of skin colour (Fig. 3 A2 and B2).

Skin colour was measured on the shaven images to ensure that hair pigment did not interfere with the reading.

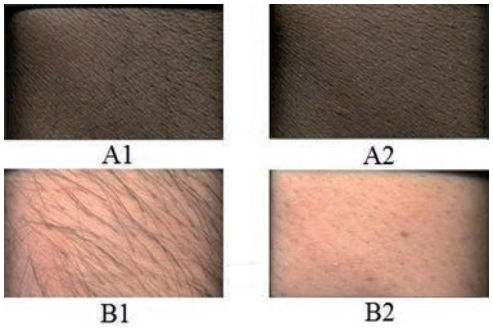

Fig. 3. A1 and B1 (before shaving) were used for follicle density measurements and A2 and B2 (after shaving) were used for skin colour measurements

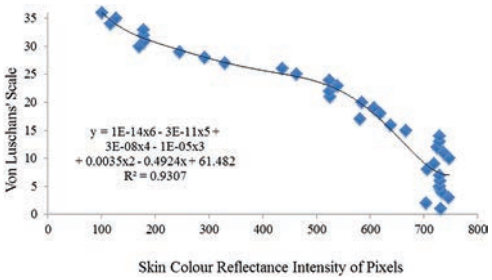

Fig. 4. Validation of methods Von Luschan's Scale and skin colour reflectance intensity of pixels

Von Luschan's Chromatic Scale and skin reflectance were used to quantify skin colour. Von Luschan's Scale, a principal method of measuring skin colour, consists of 36 differently coloured tiles from very fair (tile 1) to very dark (tile 36) (Chiao et al. 2013). Skin reflectance is measured by the amount of light reflected from the skin and is measured in wavelengths. It can be performed with the use of software (Välisuo et al. 2011). There is a good correlation between these two methods (Fig. 4). NIS BR Anatomy Software was used to measure reflectance. Greater reflectance intensity correlated with a lighter Von Luschan's tile, this was applied for the study in order to determine skin colour.

Each image of the participant shaved forearm was examined with the use of the software, and reflectance intensities of pixels were used for each individual to measure skin colour.

Statistical Analysis

Geographic origin of all participants was divided into three groups based on latitudes:

- Group 1: Equatorial areas, ranging from tropic to tropic (Tropical)
- Group 2: Intermediate latitude between a tropic and 45 degrees
- Group 3: Extreme latitude, greater than 45 degrees
- Further on, the sample was also divided into two groups according to skin colour reflectance intensity.

1. Sample with skin colour reflectance of 330 and above pixel intensity (n=6)

2. Sample with skin colour reflectance of 331 and above pixel intensity (n=70)

Following statistical analyses were carried out by the use of IBM SPSS (2010), linear regression analysis, ANOVA, t-test, F-test, correlations (Pearson's product-moment). Graphs were created by Microsoft Excel (2010).

Results

Overall, there were similarities present in follicle density and hair characteristics across the various areas of the human

Table 1. Measurements from histological analysis (n=4)

	Density per cm^2	SD	Follicle length (μm)	SD	Follicle width (μm)	SD	Hair length (μm)	SD	Hair width (μm)	SD
Chin	27.5	5.1	202.1	112.8	431.6	1297.9	105.7	70.2	159.2	338.6
Back	12.0	1.7	130.7	91.4	102.0	49.5	68.9	80.1	55.5	56.3
Pubis	8.8	1.5	203.6	154.2	202.4	156.8	127.6	121.1	97.0	86.3
Axilla	8.6	1.6	281.3	144.3	244.5	144.3	173.2	152.3	143.0	124.7
Forearm	8.1	1.1	142.0	61.8	153.5	101.1	57.7	33.2	65.0	52.0
Leg	6.6	0.8	138.3	40.7	104.9	48.9	70.2	37.0	57.5	35.8
Chest	5.1	0.5	195.0	103.6	201.5	159.7	107.3	81.9	115.4	126.0

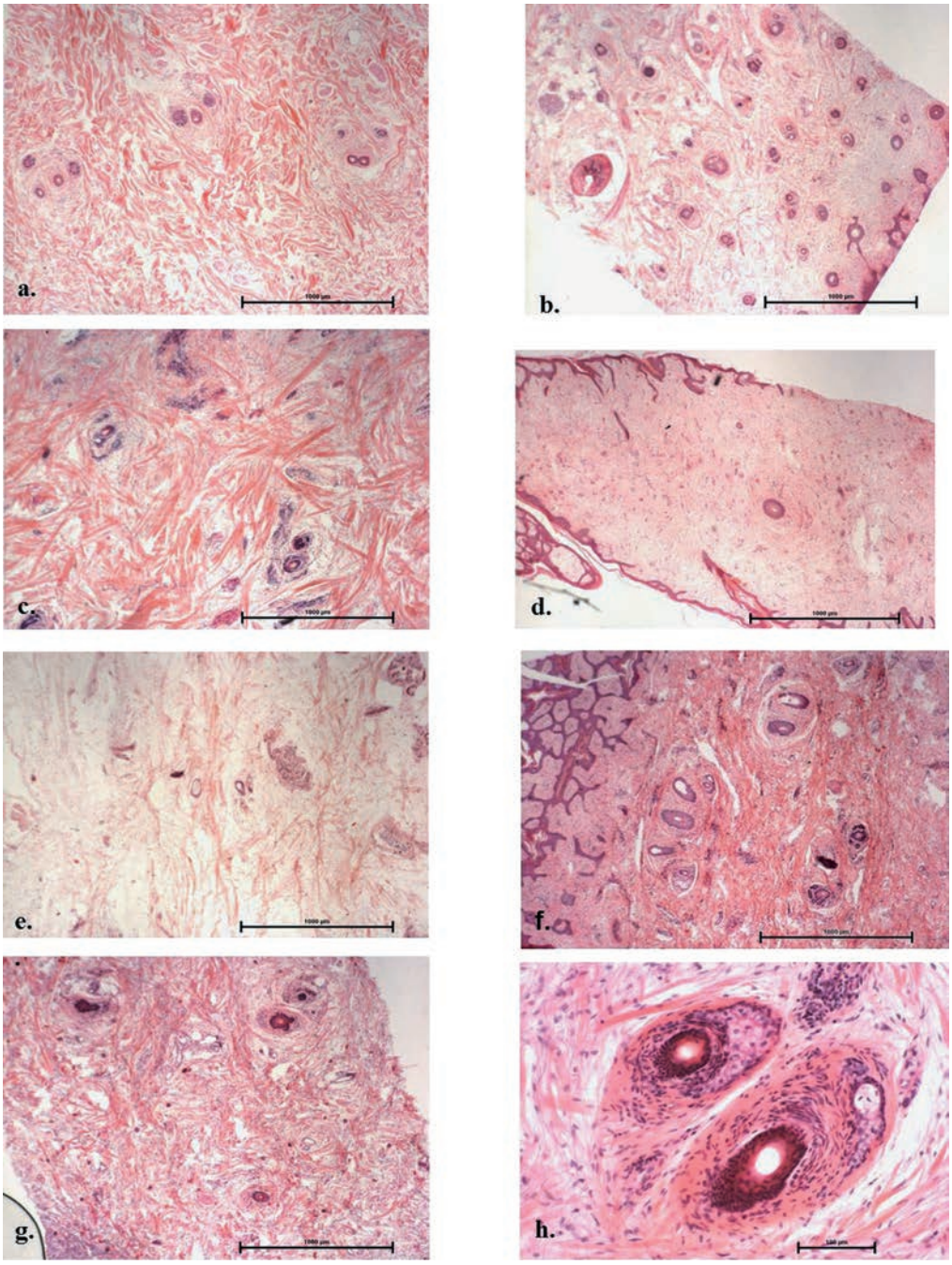

Fig. 5. H & E stained images showing follicle density a Back; b Chin; c Chest; d Axilla; e Leg; f Pubis; g Forearm all viewed at 4 times magnification and h. forearm follicles at 20 times magnification

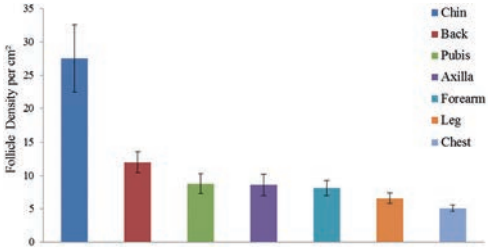

Fig. 6. Distribution of follicle density across the body with ± SD

body (Table 1). Sizes of follicles across the body were greatest on the chin, while sizes of hair within the follicles varied. Thicker hairs were found on the pubis and axilla (Table 1). With the exception of the chin and back, which had the greatest follicle density, the density was similar in all other regions (Fig. 5). This confirmed that the forearm could be used as representing the human body as its follicle density was similar to other regions.

The chest had the lowest follicle density (Fig. 6). This was as expected of a mammal; greater hair dorsally and around the limbs and less hair ventrally. No sex differences were evident, therefore sample was pooled.

Hair density, sizes and skin colour

Means, standard deviations and standard error of the mean was calculated for the entire sample (n=76) (Table 2).

There was a strong power relationship between follicle density and skin

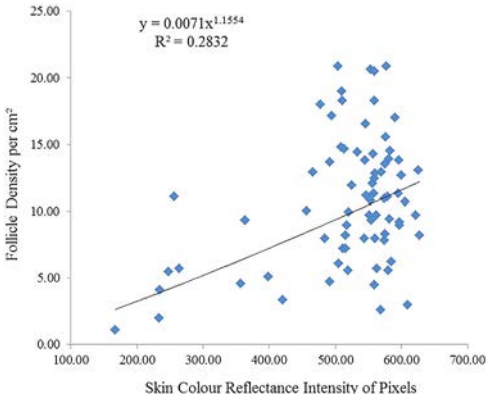

Fig. 7. Follicle density per cm2 and skin colour reflectance of all participants (n=76)

colour reflectance intensity (Fig. 7). A notable trend can be seen as a lower follicle density correlated with darker skin colour, however, there is a greater range of variation in people with lighter skin. The relationship is significant with $R^2=0.283$ ($p<0.05$).

Similarly, hair length and skin colour reflectance had a strong power relationship (Fig. 8). Shorter hair length correlated significantly with darker skin colour reflectance: $R^2=0.209$ ($p<0.05$).

In contrast, hair width did not show any significant relationship with skin colour reflectance, however there was a slight trend with $R^2=0.023$ (Fig. 9).

Initially, the sample was divided into three groups by latitude. However, upon analysis no difference was seen between groups 2 and 3 (Table 3), therefore, these groups were pooled.

Table 2. Summary of all participants (n=76)

	Mean	SD	SE	Min	Max
Skin colour reflectance intensity	515.3	100.8	11.6	167.4	627.2
Follicle density per cm²	10.7	4.8	0.6	1.2	20.9
Hair length (mm)	10.4	3.6	0.4	3.4	17.5
Hair width (mm)	0.1	0	0	0	0.1

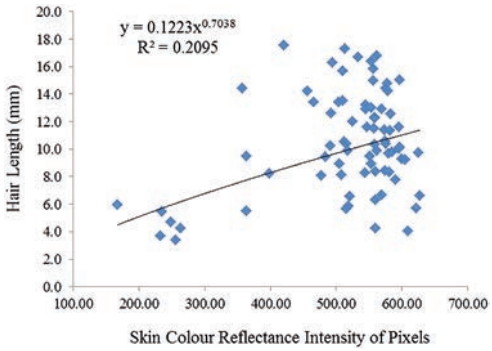

Fig. 8. Hair length (mm) and skin colour reflectance of all participants (n=76)

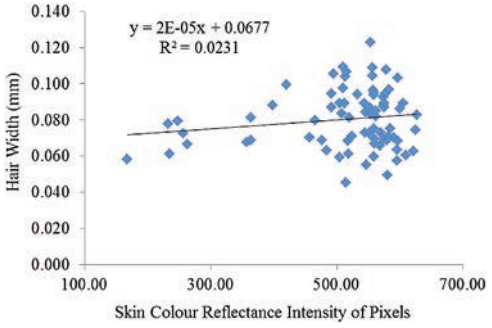

Fig. 9. Hair width (mm) and skin colour reflectance of all participants (n=76)

Thus, groups were sorted as tropical (group 1) and other (groups 2 and 3) (Table 4). There was a considerable variation noted in both groups across all variables, however, hair width had similar means in both groups with only 0.01 difference (Table 4). Standard deviations of hair width were identical in both groups (Table 4). The greatest differences were seen in skin colour reflectance (Table 4). Similar, to previous results, skin colour reflectance, follicle density, and hair length differences were significant, while hair width difference was not T values of skin colour reflectance and hair length were significant, 4.89 and 2.47 respectively; $p<0.05$

The sample was grouped by skin colour reflectance. Individuals with skin reflectance intensity reading of under 330 reflectance intensity of pixels (n=6) and over 331 reflectance intensity of pixels (n=70). Considerable differences can be seen in all variables with skin colour reflectance below 330 intensity correlating with shorter hairs and lower follicle density, in not only mean values, but also range, standard deviations and stand-

Table 3. Comparisons of means and standard deviations across latitude groups 1 (n=14), group 2 (n=19) and group 3 (n=43)

	Latitude group	Mean	SD
Skin colour reflectance	(1) Tropical	367.7	136.6
	(2) Intermediate	542.9	40.0
	(3) Extreme	551.3	52.5
Follicle density per cm^2	(1) Tropical	8.5	6.3
	(2) Intermediate	12.0	5.7
	(3) Extreme	11.0	3.5
Hair length (mm)	(1) Tropical	8.0	4.2
	(2) Intermediate	11.7	4.0
	(3) Extreme	10.7	3.0
Hair width (mm)	(1) Tropical	0.1	0.0
	(2) Intermediate	0.1	0.0
	(3) Extreme	0.1	0.0

Table 4. Summary of participants of tropical origin (n=14) and all other origins (n=62)

	Tropical mean	SD (n=14)	Other mean	SD (n=62)	t
Skin colour reflectance	367.7	136.6	548.7	48.9	4.89*
Follicle density per cm^2	8.4	6.3	11.2	4.3	1.62
Hair length (mm)	8.0	4.2	11.0	3.3	2.47*
Hair width (mm)	0.1	0.2	0.1	0.2	1.16

*$p<0.05$

Table 5. Participants with a reflectance of ≤330, dark skin (n=6) and ≥331, lighter skin colour (n=70)

		Mean	SD	SE	Range	t	F
Skin colour reflectance	≤ 330	233.8	34.6	14.1	270.2	25.70*	3.53*
	≥ 331	539.5	59.0	7.0	96.0		
Follicle density per cm^2	≤ 330	4.9	3.5	1.4	9.9	4.07*	2.04*
	≥ 331	11.2	4.7	0.6	18.3		
Hair length (mm)	≤ 330	4.7	1.0	0.4	2.6	11.13*	13.49*
	≥ 331	10.9	3.3	0.4	13.5		
Hair width (mm)	≤ 330	0.0	0.0	0.0	0.0	2.91	486.93*
	≥ 331	0.0	0.0	0.0	0.1		

*$p<0.05$

ard error of means (Table 5). Since, the data was not normally distributed cubic transformation was used to bring data distribution to normality prior to t-test. T-tests showed significance across the variables, with $p<0.05$ for all variables with the exception of hair width (Table 5). F-test of differences in variances was also significant.

Discussion

This study shows that hair development is related to skin colour, and that skin pigmentation may play a role in regulating size of hair and hair follicle density. Since this study is on humans, it could not be experimental and therefore is observational. Sampled ranges of variation were large and this permitted observations of correlation and relationships.

The sample size for this study was relatively large (n=76) exceeding twice the minimum required sample size determined by the power analysis, however, there was a small representation of those of darker skin reflectance below 330 (n=6). The results could have been more precise if the sample size of individuals with darker skin was greater. However, this was difficult to achieve due to the study taking place within the environment of the University of Adelaide, mostly attended by people descended from those born in higher geographical latitudes and not commonly by people originating in lower geographical latitudes. Another limitation included

the assessment of geographic origin of participants by questionnaire. To avoid any suspicion of possible racist bias, only birthplace of biological parents was asked by the researcher. It was hoped that parental birthplace corresponded to their geographic background. However, the researcher was mindful that parents may have been second generation emigrants born in an area that did not reflect their family lineage's place of origin. Despite this, when grouping individuals by parents birthplaces, results were still significant. Although the histology component of the study was purely aimed to view the hair variation across the human body in order to understand to what extent the forearm hair represents the human body, the sample size was dictated by limited time for multiple dissections and histological analyses. This limited sample size may not have permitted statistical observation of subtle differences. Since all cadavers were of European geographic background there was not much variation noticeable in their skin colour. Any measurement errors always reduce levels of correlations (Padilla and Veprinsky 2012).

Despite all limitations described above, this study showed the relationship between hairiness and skin pigmentation which has not been studied before. Significant product- moment correlations and significant differences in simple comparison of the means of people grouped by skin colour indicate an inverse relationship between skin pigmentation and hairiness. It seems from this study that there is a one way correlation between greater concentrations of melanin and shorter and less dense hairs. Contrastingly, in those individuals who did not have greater concentrations of melanin the whole range of hairiness is seen (see results: Fig. 7). Although both the range of skin colours and the range of hairiness are wide in the sample with reflectance over 330, there is no correlation between these variables in this sample (R^2=0.120). There is also a significant difference in variances. Individuals of lighter skin pigmentation have much wider variation of hair characteristics from that of darkly pigmented people. People of lighter skin sometimes have fairly large hair dimensions and large hair densities that are easily noticeable with the naked eye as a "pelage".

Most theories about human hairlessness are based on supposed adaptive value of hairlessness, whereas it seems to be a correlate, or possibly a consequence, of increased concentrations of melanin. Skin colour has long been established as an indicator of adaptation to increased UV conditions (Jablonski & Chaplin 2000) while the question of human hairlessness does not find a satisfactory answer. The wider range of hairiness found in less pigmented people seems to indicate that hairlessness is not a consistent human characteristic. It is only noticeable consistently in people with greater concentration melanin in superficial skin layers (Costin and Hearing 2007); this may be interpreted in evolutionary terms as follows.

When human ancestors ventured out of shaded forests into areas exposed for prolonged periods to high and consistent UV radiation (open savannah or waterside environments) (Schwartz and Rosenblum 1981) the terminal hairs (likely to be similar to those of present day apes), did not provide sufficient insulation against detrimental UVB radiation, especially in areas of the body exposed to UV by assuming erect bipedal posture (e.g. chest and abdomen) (Hoch-

berg and Templeton 2010). Thus, high melanin concentration located in basal layer of the epidermis (above the dermis) became an effective protection against UV (Mc Neil et al. 2013). This relocation of melanin from deeper skin layers to the basal layer (Becker 1927) may have competed with hair growth or deregulated hair growth in the skin, thereby, reducing size of hairs. Were hairlessness developed before changes in concentration of melanin in the superficial skin layer, all humans including those who lost skin pigment, would be equally hairless.

In future studies it is necessary to better document hair characteristics of highly pigmented people. To find eventual physiological mechanisms of the interactions between high concentration of melanin and hair follicle growth and development may require some animal experimentation.

Dark skin pigmentation is invariably related to less hairiness, while lighter skin pigmentation displays a full range of hairiness. This finding suggests that human ancestors in high UV areas needed to develop high concentrations of melanin first, consequently leading to the reduction in hair. In contrast, in individuals exhibiting reduced melanin concentration a full range of hairiness can still exist.

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Authors' contributions

AD wrote the final version of the paper. AD, MH and JK jointly formulated the research hypothesis, plan and method. AD collected observations and analysed them with MH and JK help. All authors contributed to final interpretation of the results, and read the final version of the text.

Conflict of interest

The Authors declare that there is no conflict of interests.

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