Current research on ethnic hair

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This study collected qualitative and quantitative data about the morphology, structure, geometry, water swelling, and mechanical properties of hair fibers from subjects of different ethnic origins. X-ray analysis, cross-sectional measurements, tensile testing, and water swelling were performed on samples of hair collected from Caucasian, Asian, and African subjects. No differences in the intimate structures of fibers were observed among these 3 types of hairs, whereas geometry, mechanical properties, and water swelling differed according to ethnic origin. In addition, the behavior of hair fiber under mechanical stress was visualized with environmental scanning electron microscopy. (J Am Acad Dermatol 2003;48:S115-9.)

Human hair is categorized into 3 major distinct groups according to ethnic origin: Asian, Caucasian, and African. Although a considerable amount of data has been reported on human hair, very few data on the influence of ethnic origin on hair characteristics are available.

- Diameter and section: Asian hair has a greater diameter with circular geometry. African hair presents a high degree of irregularity in the diameter of hair along the hair shaft with an elliptic section. Caucasian hair has an intermediate diameter and section shape.[1-4]
- Shape of fiber: African hair has a physical shape resembling a twisted oval rod, whereas Caucasian and Asian hairs are more cylindric.[3] African hair shows frequent twists, with random reversals in direction and pronounced flattening.[2]
- Mechanical properties: African hair generally has less tensile strength and breaks more easily than Caucasian hair.[2,4]
- Combability: African hair is more difficult to comb than Caucasian hair because of its extremely curly configuration.[4]
- Chemical composition: Proteins and amino acids constituting keratin are similar in African, Asian, and Caucasian hair.[3,5-7]
- Hair moisture: African hair has less moisture content than Caucasian hair.[4]

The findings of investigational studies we performed on African, Caucasian, and Asian hairs are reported here.

HAIR SAMPLES

The hair samples used in this study were cuttings collected from volunteers. Virgin hair samples (defined as hair that has not been chemically treated) were taken from subjects living in France or the United States for African hair, in China or Japan for Asian hair, and in Europe or Canada for Caucasian hair. Before any measurement, the hair samples were washed with a clarifying shampoo, rinsed, and air dried.

STRUCTURE OF HAIR KERATIN: X-RAY ANALYSIS

A number of studies have been conducted to identify the protein structure of mammalian hair, wool, and, especially, human hair. Nevertheless, to our knowledge, the protein structure analyzed by x-ray diffraction for the 3 major ethnic groups has never been studied. This technique enables an organizational approach toward the 3-dimensional structure of hair. It especially determines the location of crystalline and amorphous structures of keratin into the structural organization of hair, whereas the existing analyses of keratin were essentially focused on chemical composition. X-ray analyses were conducted with a synchrotron at the European Synchrotron Radiation Facilities, Grenoble, France.

Observations were made with a 5-μm–diameter collimated monochromatic incident beam with a wavelength of 0.948 Å. The fiber axis was oriented perpendicular to the incident beam. A diffraction pattern, which can be analyzed from 3 to 200 Å, was obtained. The results are based on hair samples taken from 5 different individuals per ethnic group.

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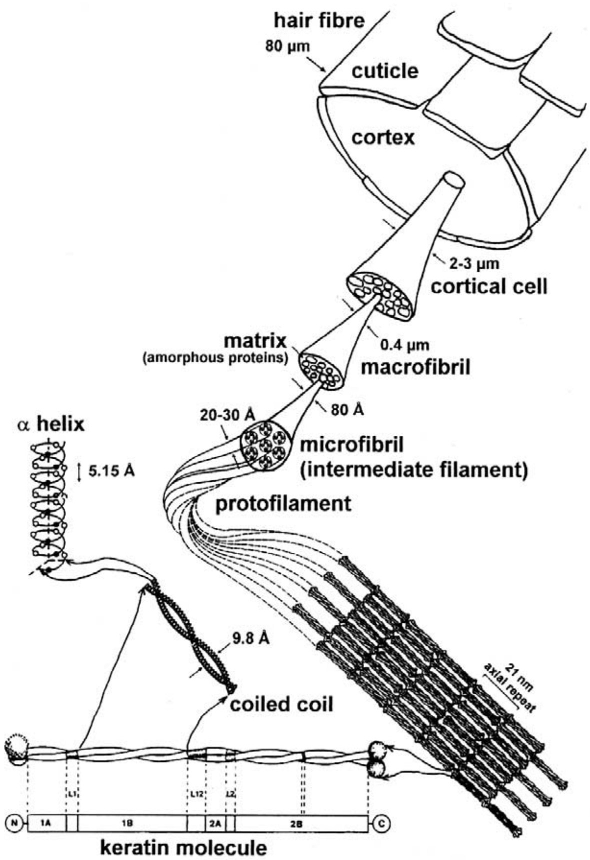

Fig 1. Hair structure scheme.

Different areas in the hair structure are shown according to the structure scheme presented in Fig 1. The meridian reflection at approximately 5 Å is divided into 2 signals: a large maximum at 5 Å that corresponds to the coiled coil axis of the α-helix and a finer one at 5.15 Å that represents the periodicity of the keratin molecule arrangement along the microfibril. Another signal of the α-keratin structure is defined by the broad diffuse maximum located at approximately 9.8 Å on the equator, which corresponds to the more or less regular distance between 2 strands in a coiled coil.[8,9]

The supercoiled coil structure formed by the keratin chains, usually designated as protofibril, gives rise to various meridian reflections. The most intense one is located at approximately 67 Å, characteristic of the repeat unit of several coiled-coil molecules arranged in a semicrystal configuration, the microfibril (also named intermediate filament).[10] Keratin microfibrils are packed into macrofibrils in a paracrystal configuration, and the space between microfibrils is filled by an amorphous matrix. This arrangement produces an intense and rather broad scattering signal located on the equator at approximately 90 Å.[11]

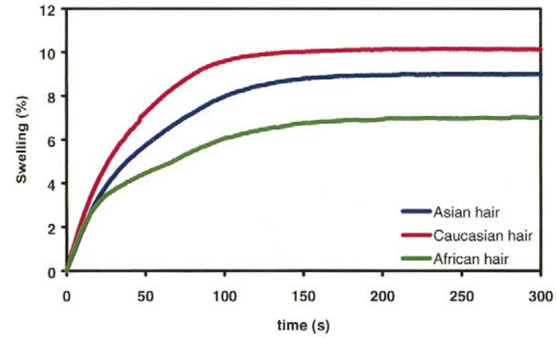

Fig 2. Radial swelling in water.

These characteristics and their locations on the pattern were determined in the 3 major ethnic groups. Regardless of the organization level considered (α-helical arrangement and coiled-coil structure, intermediate filaments, or macrofibrils), we did not observe any difference in the structure of the proteins among the 3 types of hair: African, Asian, or Caucasian. The same structure of keratin fiber in African, Caucasian, or Asian hair was observed.

RADIAL SWELLING IN WATER

The radial swelling of hair was determined by using a specific Palmer device developed in our laboratories. The principle of the method is based on a measurement of the displacement of a sensor in contact with a small portion of a hair. A 3-mm–long hair sample was placed under a sensor. After measuring the initial diameter, a drop of distilled water was introduced with a syringe under the sensor. The evolution of the diameter of the fiber consecutive to the absorption of water was measured.

The maximum swelling percentage and the swelling rate (initial slope of the curve) were evaluated from the kinetic curve. Fig 2 shows the curves obtained from each ethnic group. Twenty hairs from 1 individual of each ethnic origin were studied, and for all samples, the middle part of the hair fiber was always analyzed. Each curve was the mean of 20 measurements. African hair appears to have the lowest radial swelling rate, whereas Asian and Caucasian hair have similar higher rates. These results are statistically significant.

Because of the flattened shape of African hair, some distortion in the evaluation may have occurred. To take into account any possible distortion in the measurement, comparison of the radial swelling properties of each different type of hair was performed as a function of the initial diameter.

Fig 3 shows that the variation of diameter as a function of ethnic origin of hair is between 50 and 85 μm. For a given initial fiber diameter, Caucasian and Asian hair have the same radial swelling percentage,

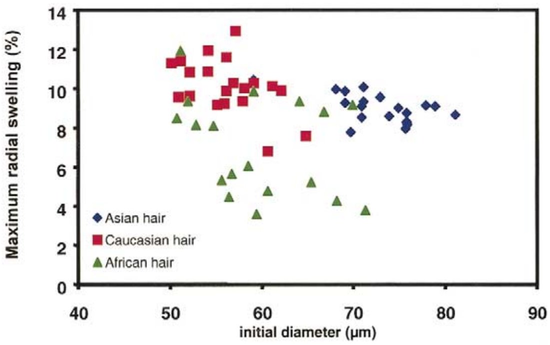

Fig 3. Radial swelling as a function of hair diameter.

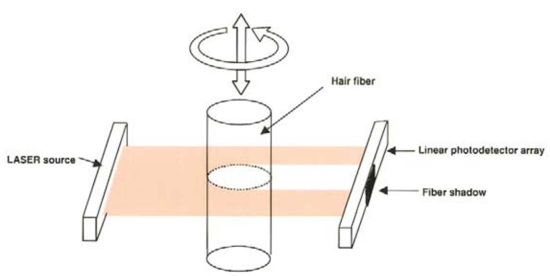

Fig 4. Device used for geometry and morphology analysis.

whereas African hair has a lower percentage of swelling. African hair has a lower swelling percentage in water than Caucasian and Asian hair. There is no valid explanation for this result, because hair composition and structure, as determined by x-ray analysis, do not differ for the 3 types of hair.

GEOMETRY AND MORPHOLOGY ANALYSIS

Geometric measurements were achieved with a new optical device that enables a 3-dimensional reconstruction of fiber morphology (Fig 4). The device was designed in our laboratories with an Image Tracer IT 5000 S/N 135 (Zimmer KG, Rossdorf, Germany) for the optical part. Hair fiber was drawn on a bow allowing the fiber to rotate (step 12°) and move up and down (scan amplitude 5-500 μm) in a laser beam.

The fiber was placed between the light source and a linear photodetector array. The shadow of the fiber was recorded on the linear photodetector array. Characteristic parameters, such as mean diameter and mean cross section of the fibers, were obtained from raw data. For each sample (14 African hairs, 4 Asian hairs, and 11 Caucasian hairs), 3 parts were analyzed: the root, the middle, and the tip end.

The ellipticity is given by the ratio $e = \frac{\text{small diameter}}{\text{large diameter}} \times 100$. The more circular the section, the higher the ellipticity ratio. Ellipticity is low for African hair (the section is a flat oval) and high for Asian hair (Asian hair exhibits an almost circular section).

The variability is given by the ratio $\frac{\text{standard deviation}}{\text{mean value}} \times 100$ and quantifies the heterogeneity of the data. The more heterogeneous the section, the higher the variability.

Hair characteristics can be given in 2 ways: (1) The means of each characteristic measured on the sample can be drawn to describe an "average hair model" of each ethnic group. (2) The intra-ethnic data can be calculated using the mean for the whole population studied to describe the variability within an ethnic group.

From the data gathered in Table I, 4 major points are observed:

1. The cross-sectional area of African and Caucasian hair is quite similar. The cross-sectional area of Asian hair is the largest.
2. The most elliptic cross-sectional shape is observed in African hair, with a mean ellipticity of less than 60%, whereas Asian hair exhibits a mean ellipticity of 90%, corresponding to an almost circular cross section. Caucasian hair shows an intermediate elliptic shape (ellipticity approximately 75%).
3. In terms of variability, African hair shows the greatest percentage of section variability, compared with Asian and Caucasian hair. The variation of the African hair cross section confirms the presence of regular restrictions of the cross section along the fiber. This observation is very important in regard to mechanical properties.
4. The intra-ethnic variability of the ellipticity observed in African hair (approximately 13%) is higher than that observed in Asian or Caucasian hair (approximately 5%-6%). The intra-ethnic variability of the section is higher in Caucasian hair compared with that observed in Asian or African hair.

MECHANICAL PROPERTIES

The mechanical properties of wool and Caucasian hair have been widely described, but to our knowledge the mechanical properties of Asian, African, and Caucasian hair have never been studied together under the same experimental conditions. We performed a tensile study under dry conditions (45% relative humidity) using a DIA-STRON MTT600 (DIA-STRON Ltd., Hampshire, UK) on 100 individual fibers taken from 1 individual per ethnic group. Fig 5 shows the load curves for each type of hair.

The breaking stress and breaking elongation of

Table I. Geometric characteristics

Geometric data	African	Asian	Caucasian
		Average sample	
Small diameter (μm)	55 ± 2	70 ± 1	60 ± 1
Large diameter (μm)	98 ± 2	86 ± 1	80 ± 1
Section (μm^2)	4274 ± 215	4804 ± 159	3857 ± 132
Section variability (%)	8.2	3.5	3.5
Ellipticity (%)	57 ± 3	82 ± 4	76 ± 4
		Intra-ethnic variability	
Section range (μm^2)	2200–6500	3000–8000	1400–6300
Section variability (%)	24.6	26.1	34.8
Ellipticity variability (%)	12.5	5.1	5.9

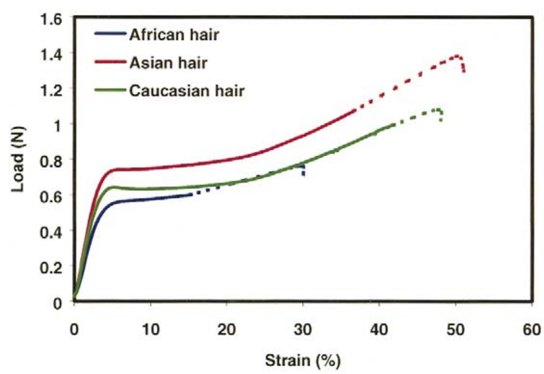

Fig 5. Load and strain curves of African, Asian, and Caucasian hair.

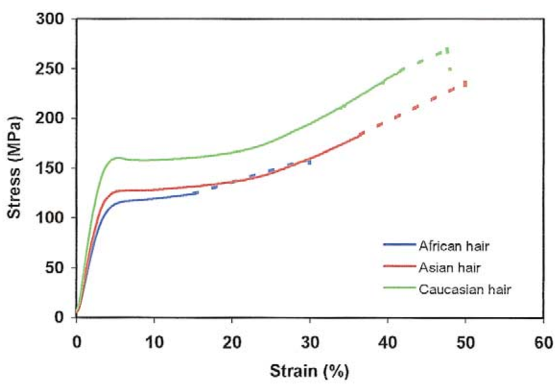

Fig 6. Stress and strain curves of African, Asian, and Caucasian hair.

African fibers are lower than those obtained in Asian and Caucasian hairs. In other words, African hair is more fragile and breaks earlier than Asian and Caucasian hairs that appear stronger and more resistant.

As shown in Table I, the section varies as a function of ethnic origin. The tensile strength of a fiber is highly dependent on its section size. To take into account the influence of section, the stress and strain curve was established (Fig 6). The stress corresponds to the nominal stress obtained after dividing the load by the section of hair, and the strain corresponds to the engineering strain obtained after dividing the elongation by the nominal length of the sample and multiplying by 100.[1]

Although Asian hair has a larger diameter and consequently a higher tensile force than Caucasian hair, these 2 types of hair exhibit a very similar behavior during strain. African hair differs from both Caucasian and Asian hairs essentially by an earlier breaking time and a lower stress requirement at breaking.

To date, there is no rationale to explain this phenomenon, because neither structural nor chemical composition differences were observed in the 3 types of hair. However, several hypotheses based on morphologic and geometric considerations of African hair could provide an explanation for such mechanical characteristics, that is, the natural constrictions along the fibers, twisted shape of the fibers, and presence of microcracks or fractures in the fiber.[12-15]

The high prevalence of fractures in African hair and the high variability of its cross section along the fiber may account for the brittleness of this type of hair, which is experienced every day by people of African origin during combing and grooming.

ENVIRONMENTAL SCANNING ELECTRON MICROSCOPY

In this study, we used a specific microscope to visualize hair fiber during breakage: the environmental scanning electron microscope (ESEM)[16] (Philips Electron Optics, Eindhoven, The Netherlands). This microscope enabled us to observe the behavior of hair fibers in an ambient environment. We used an XL30 ESEM in which a tensile stage (DEBEN UK Ltd., Suffolk, UK) was fitted. Vacuum in the chamber was set higher than the water vapor tension. The experiment was conducted at room temperature and under approximately 5 Torr. These

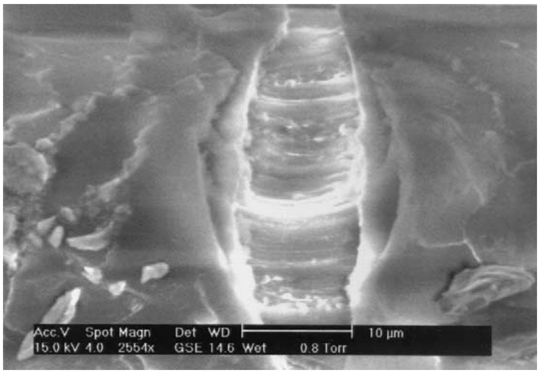

Fig 7. Focus on a hair fracture. Macrofibrils of the cortex can be observed through the opening of the cuticle. (Hair has been maintained at 0.8 Torr during image acquisition to achieve better contrast; no modification of the sample has been observed during image acquisition.) An environmental scanning electron microscope (ESEM) picture.

conditions correspond to 50% to 60% relative humidity. A computer controlled the tensile stage and displayed the stress and strain curve in real time. The 1-cm–long segments of African hair fibers were mounted on the stage and stretched at a rate of 2 mm per minute. During a 30% elongation of the hair fiber, the cuticle cells erected and cracks appeared until the cuticle completely fractured. Macrofibrils of cortex were seen through the opened cuticle (Fig 7). The ESEM proved to be an extremely powerful tool for studying hair fibers under mechanical stress, especially African hair, which is more prone to breakage.

CONCLUSION

Although our studies were performed with a small sample size, our results on the morphology, geometry, and mechanical properties of hair obtained with new investigational methods clearly confirm previously reported results in the literature concerning African hair in terms of the heterogeneity of diameter (presence of constrictions of the cross section along the fibers), ellipticity, and weakness. The main original features of our work are the x-ray micro-diffraction experiments that show the great homogeneity of the structural organization of hair keratin irrespective of the ethnic group. In addition, the ESEM proved to be an extremely powerful tool for studying hair fibers under normal conditions and therefore opens new fields of investigation.

The second major conclusion of our work is that African hair demonstrates a particular behavior when placed in contact with water. Its radial swelling percentage is lower than that observed in Asian or Caucasian hair. Because the 3 types of hair showed no differences in their structural nature or amino acid composition, the most likely explanation for differences in hydration properties specific to African hair lies in the potential differences to be found in other aspects of fiber composition, particularly in regard to lipids (which have not been investigated adequately). Further biochemical studies are required to understand these specific features to propose hair products that meet the specific needs of African hair.

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