9 Applied Science

9-1 Structural Analysis of Human Hair Fibers Using Scanning Microbeam SAXS

Human hair is one of the many keratinous fibers observed in nature and has diameters typically varying between 40 and 150 μm. Figure 1 illustrates the structure of human hair fiber. The surface of the fiber is covered with thin scale-like cells (cuticles), and the inside is filled mostly with cortical cells which are mainly composed of intermediate filaments (IFs) surrounded by matrix proteins. In some cases a medulla is present at the center of the fiber.

Human hair fibers exist in various shapes, ranging from strongly curled to nearly straight. To understand the cause of hair curliness is a major issue for the cosmetics field, however the relationship between the internal nanostructure of individual fibers and macroscopic hair shape has not yet been fully revealed.

The purpose of this study is to analyze the IF arrangement of curly and straight hair in an attempt to elucidate differences in macroscopic curl shape from the viewpoint of the internal nanostructure. Measurements have been performed for Asian, Caucasian and African hairs having various curl strengths.

Small-angle X-ray scattering (SAXS) experiments were carried out at BL-4A of the PF, and some of the Asian and African hair fibers were also subjected to measurements at BL40XU of SPring-8 [1]. The size of the incident X-ray beam was about 5 μm. Single hair fibers were translated in directions perpendicular to the X-ray beam with a step size of 5 - 10 μm, and two-dimensional SAXS patterns were recorded at each position. In this study, only the scattering patterns from the cortex have been analyzed.

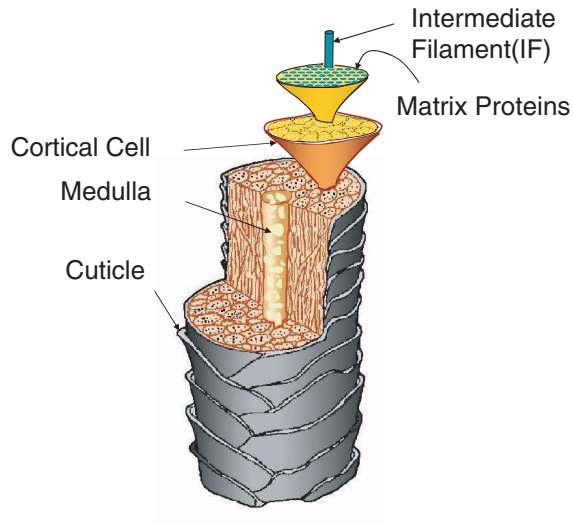

Figure 1
Internal structure of human hair and the hierarchical structure of a cortical cell.

Figure 2 shows typical SAXS patterns recorded for curly and nearly straight human hair fibers at BL-4A. The major intensity maxima along the equator (short arrows) are attributed to lateral packing between IFs. For

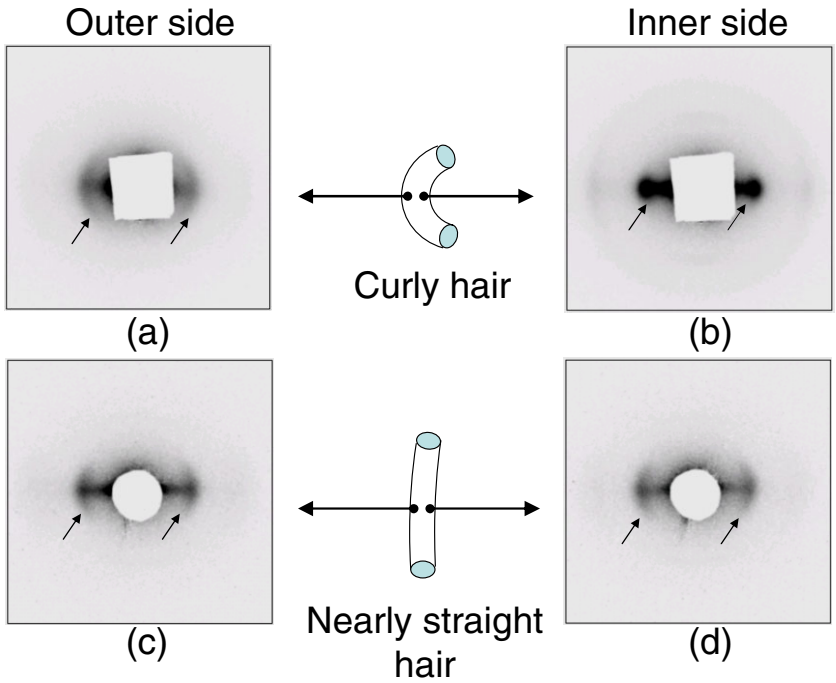

Figure 2
SAXS patterns recorded at the outer side (a), (c), and the inner side (b), (d), of fibers of curly and nearly straight hair.

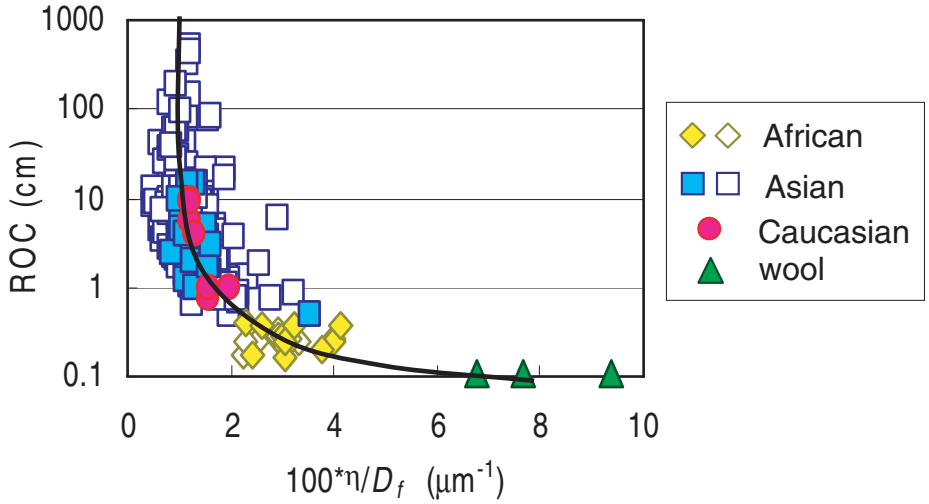

Figure 3
Dependence of the macroscopic curl strength (radius of curvature: ROC) on the microscopic inhomogeneity of the IF arrangment (see text). The filled symbols denote data recorded at the Photon Factory, the unfilled symbols data recorded at SPring-8.

curly hair, a clear difference in these IF peaks is seen between the outer and inner sides of the fiber, as shown in Figs. 2(a) and 2(b). The IF peaks recorded at the inner side are strong and sharp, while those at the outer side are weak and broad. This means that the IF arrangement is inhomogeneous in the transverse direction of the hair fiber. Contrary to curly hair, nearly straight hair shows no such difference, suggesting that the degree of inhomogeneity is related to the curl strength.

In order to quantify the spatial inhomogeneity of the IF arrangement, the full-width at half maximum (FWHM) of the IF peak profile in the azimuthal direction was evaluated for various hair samples, and the ratio of FWHM obtained from the outer side to that from the inner side, η was calculated for each sample. Figure 3 displays the macroscopic curl strength (radius of curvature: ROC) vs. η normalized by the fiber diameter, D_f, for human hair of three major ethnic groups and also Merino wool [2] as an extreme case. It was found that curl shape does indeed depend on the inhomogeneity of FWHM in the transverse direction and, moreover, all the data seem to follow one unique curve. Consequently, it is strongly suggested that the curl shape of hair originates from the spatial inhomogeneity of the IF arrangement, and this relationship between macroscopic hair shapes and the internal nanostructure is expected to hold for hair fibers of all ethnic origin, even including wool.

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References

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[2] Y. Kajiura, S. Watanabe, T. Itou, A. Iida, Y. Shinohara and Y. Amemiya, *J. Appl. Cryst.*, **38** (2005) 420.