Imaging of Damaged and Undamaged Hairs using X-Ray Microtomography

The market of hair-care products in Japan is large with about 200 billion yen sales per year. In particular, damage care is important because of the increasing opportunities to perform hair coloring, bleaching and permanent waving in Japanese consumers. To evaluate the degree of hair damage, many methods such as tensile strength, flexibility and amino acid analyses, are developed. However, structural information on hair damage, such as that on the locations of damaged parts and how hair damage proceeds in these location, seems insufficient. Electron and atomic force microscopes have been used for damaged hair observation. However, they cannot provide a three-dimensional microstructure of hair, and sometimes, they need specific preprocessing techniques, for example, slicing and staining. Thus, we aim to obtain a three-dimensional microstructure of hair without preprocessing. This structural information is expected to provide new aspects on care methods for damaged hair.

Beamline **BL47XU** was designed for application to various imaging technologies. It is mainly used for experiments involving X-ray photoelectron spectroscopy and microtomography in a hard X-ray region. X-ray computerized tomography (CT), which was originally developed for medical diagnosis, is a nondestructive technique for three-dimensional observation using a strong penetrating power of X-rays. Recently, a CT method with a high spatial resolution (X-ray microtomography, XMT) has been developed. Using highly collimated X-ray beams from a synchrotron radiation light source and using a high-spatial-resolution image detector, XMT with a simple projection geometry reaches a spatial resolution of 1 μm [1]. On the other hand, X-ray microscopy using several types of X-ray imaging device, such as a Fresnel zone plate (FZP), refractive lenses, and total reflection mirrors, has been developed. Currently, a spatial resolution of several tens of nm is achievable in the hard X-ray region. For example, the spatial resolution of 30 nm has been achieved with a FZP [2]. Therefore, combining such X-ray microscopy optics with XMT is expected to result in very high spatial resolution three-dimensional imaging.

Edge-enhanced refraction contrast imaging can also be realized with the slightly off-focus condition of the X-ray microscopy optics. This method enables the observation of light materials, whose absorption is too small in the hard X-ray region to observe with absorption contrast [3,4]. By this method, the three-dimensional microstructure of hair without preprocessing could be obtained. Figure 1(a) shows an X-ray transmission image of a human hair not subjected to any chemical treatment. Using a series of transmission images, CT images are produced. One of the CT images is shown in Fig. 1(b). Hair consists of three parts, namely, medulla, cortex and cuticle. Features of these parts are observed in this sliced section image.

To obtain a three-dimensional image, layers of CT images are piled on top of each another. Figure 2 shows a three-dimensional image of hair without chemical treatment. This image shows features of the cuticle, cortex and medulla. In the cortex, some microstructures of submicron size are aligned in the length direction of a hair shaft. In addition, these

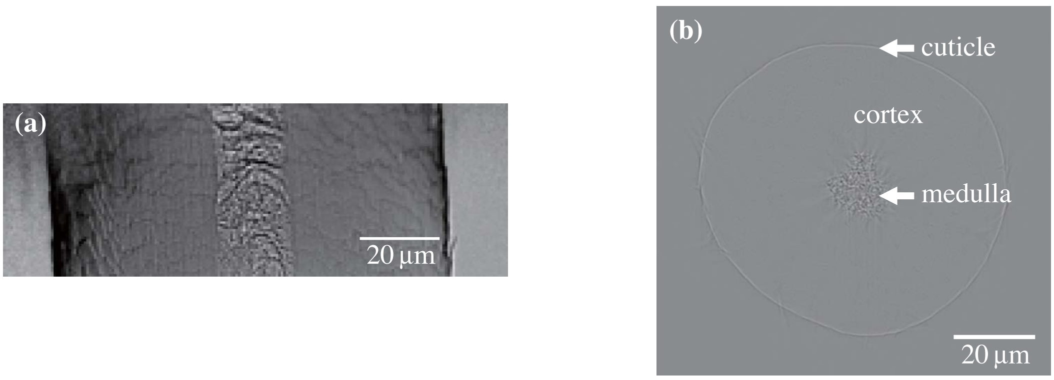

Fig. 1. **(a)** X-ray transmission image of hair obtained in off-focus edge-enhance mode. **(b)** CT image. X-ray energy: 9.8 keV; pixel size: 88 nm.

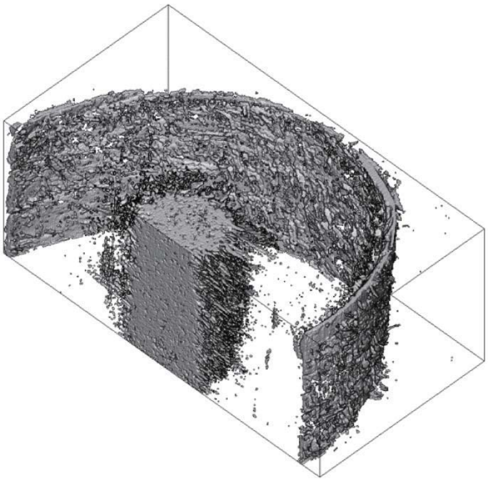

Fig. 2. Three-dimensional image of hair without chemical treatment.

microstructures increased by chemical treatments (e.g., permanent waving), as shown in Fig. 3. Edge-enhanced refraction contrast imaging enables the observation of the boundary between two structures with different electron densities. We consider that the microstructures in the cortex are cavities produced by chemical treatments, such as permanent waving. The number of microstructures was observed to proportionally increase with the extent of damage. In addition, the number of microstructures tended to decrease with repair treatments using a certain kind of oil.

Using edge-enhanced refraction contrast imaging, the three-dimensional microstructure of hair could be observed without the preprocessing of hair samples. We found that the number of microstructures in the cortex increased with chemical treatments. Although other experiments will be conducted to confirm the structural change quantitatively, the increase in the number of microstructures seems to provide a new aspect of hair damage. Edge-enhanced refraction contrast imaging is a useful tool for hair science.

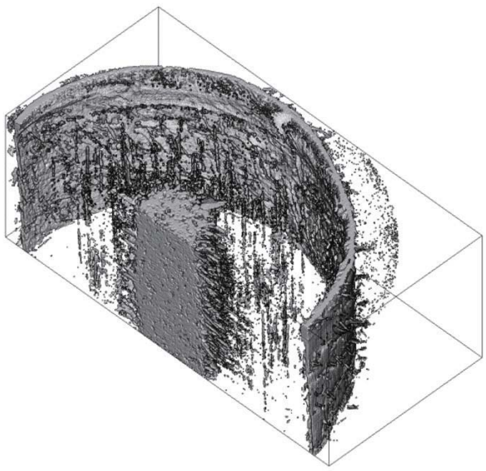

Fig. 3. Three-dimensional image of hair with chemical treatment (permanent waving).

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