Disruption of human stratum corneum lipid structure by sodium dodecyl sulfate

The skin maintains the body temperature and forms the outer barrier of the human body, protecting it against various environmental hazards, including exposure to chemical stimulants, poisons, microbial invasions, hazardous ultraviolet radiation, and other possible physical and chemical hazards. Furthermore, its low permeability to water protects the body from excessive dehydration. Maintenance of an optimal functional state requires that the skin be kept clean. Detergents are major ingredients of body soaps and cleansers. However, harsh detergents can damage the skin. The stratum corneum (SC) is the outermost layer of the skin and it contains corneocytes and intercellular lipids, which form lamellar structures. These well-organized structures are especially important for the barrier function of the skin, and detergents may impair this function by disrupting the lamellar structure. We used X-ray diffraction to evaluate structural modifications in human SC resulting from sodium dodecyl sulfate (SDS) treatment, focusing on how SDS affects SC lipid structures such as the lamellar structure and the hydrocarbon-chain packing structures. We investigated structural changes in isolated human SC using small- and wide-angle X-ray diffraction.

Human SC sheets were obtained from Biopredic International (Rennes, France). The dried samples were rehydrated in an incubator until they were 25 wt% hydrated. Reagent-grade SDS was purchased from Wako (Japan). Solutions with 1 wt% and 10 wt% SDS were prepared in Carmody buffer (pH 7.0). The X-ray diffraction measurements were performed using SPring-8 **BL19B2** and **BL40B2** beamlines. The method used is particularly useful for detecting small changes in the SC structure [1]. The measurement specifications of BL19B2 were as follows. All samples were exposed to an X-ray beam at 28 keV for 30 s at approximately 25°C. An X-ray beam with 200 μm diameter was used to allow the observation of the whole SC sample. A photon-counting pixel array detector (PILATUS 2M, Dectris) was used. The camera length, i.e., the distance between the sample and the detector, was *ca.* 700 mm. The measurement specifications of BL40B2 were as follows. All samples were exposed to an X-ray beam at 15 keV for 30 s at about 25°C. The camera length was *ca.* 500 mm. The diffraction pattern was obtained with a 300 mm × 300 mm imaging plate (R-AXIS, Rigaku). A wide-*q*-range X-ray diffraction profile was recorded every 3 min.

The SAXD profiles for the long lamellar structure of human SC after treatment with 10 wt% SDS, 1 wt% SDS, and without SDS (i.e., with distilled water) up to 129 min are shown in Figs. 1(a), 1(b), and 1(c), respectively [2]. Treatment with 10 wt% SDS led to the third-order peak of the long lamellar structure at about $S = 0.22$ nm^{-1} being smeared out with time as shown in Fig. 1(a). Treatment with 1 wt% SDS led to similar behavior for the third-order peak. Without SDS, the third-order peak did not change. The very weak fourth-order peak of the long lamellar structure at about $S = 0.29$ nm^{-1} became weaker after the SDS treatments, similar to the behavior of the third-order peaks in both the 10 wt% and 1 wt% SDS treatments, and the peak at about $S = 0.29$ nm^{-1} remained unchanged when distilled water was applied. These

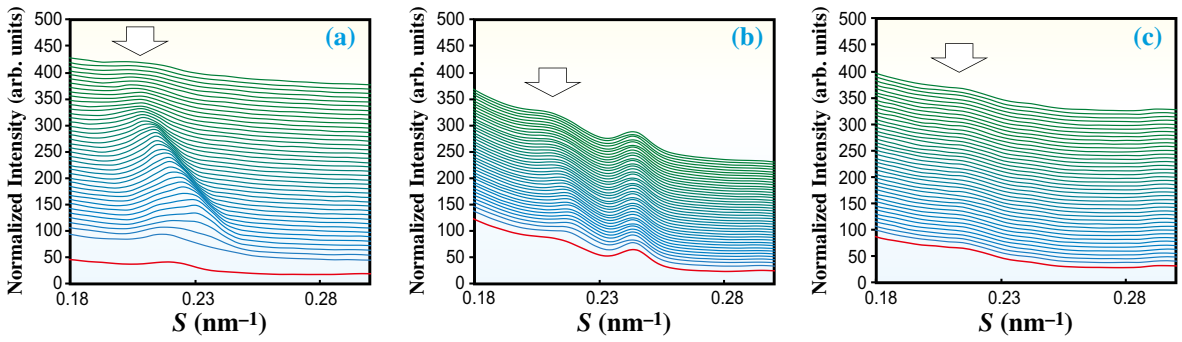

Fig. 1. SAXD profiles of human SC treated with 10 wt% SDS **(a)**, 1 wt% SDS **(b)**, and without SDS **(c)**. The profiles before treatment are indicated by a red curve. The profiles after treatment were recorded every 3 min up to 129 min. The illustrated intensity profiles are shifted in the vertical direction successively from blue to green curves with time. The white arrow denotes the third-order peaks for the long lamellar structure. The peak at 0.24 nm^{-1} in (b) is due to neutral lipids, which were sometimes observed.

results clearly indicate that the change in the long lamellar diffraction peak profile was caused by SDS. On the other hand, the short lamellar structure was not influenced by SDS treatment. Additionally, the intensities and the positions of peaks corresponding to hydrocarbon-chain packing structures did not change markedly both after SDS treatment of the SC and treatment without SDS. On the basis of these findings, we propose that the long lamellar structure is predominantly affected by the SDS treatment.

Upon 10 wt% SDS treatment, the X-ray diffraction peak for the long lamellar structure became broad and the intensity gradually diminished. To investigate this behavior further, the third-order X-ray diffraction profile at about $S = 0.22\ \mathrm{nm}^{-1}$ was analyzed using two Gaussian functions. The final disordered lipid state was reached through two types of structural change, where one exhibits a strong diffraction peak and the other exhibits a weak peak. We propose that the disordered lipid state results from the incorporation of SDS into the long lamellar structure through the two processes. As shown in Fig. 2, the structural change for 1 wt% SDS treatment exhibited similar behavior to the strong diffraction peak for 10 wt% SDS treatment, but owing to the weak effect, the behavior corresponding to the strong peak predominantly occurred.

This study clearly demonstrated the process of human SC collapse caused by detergent. Bouwstra *et al.* [3] and Kuemple *et al.* [4] pointed out that the long lamellar structure in skin plays an important role in maintaining the skin barrier function. Therefore, the observed effect of surfactants on the long lamellar structure should be considered in the development of cleansers.

In an experiment involving washing women's arms in SDS, transepidermal water loss (TEWL) values temporarily increased and skin capacitance decreased. In other words, the change in the long lamellar structure plays a key role in the development of dry skin after using detergents. On the basis of these studies, we developed new body soap products that can maintain the skin capacitance after taking a bath.

Recently, Mojumdar *et al.* [5] pointed out that water molecules are stored in two crystallographic locations of the long lamellar structure. We also speculate that SDS was incorporated in the two locations and, as a result, two types of structural change took place. Further detailed study on the permeation of SDS in SC is now in progress.

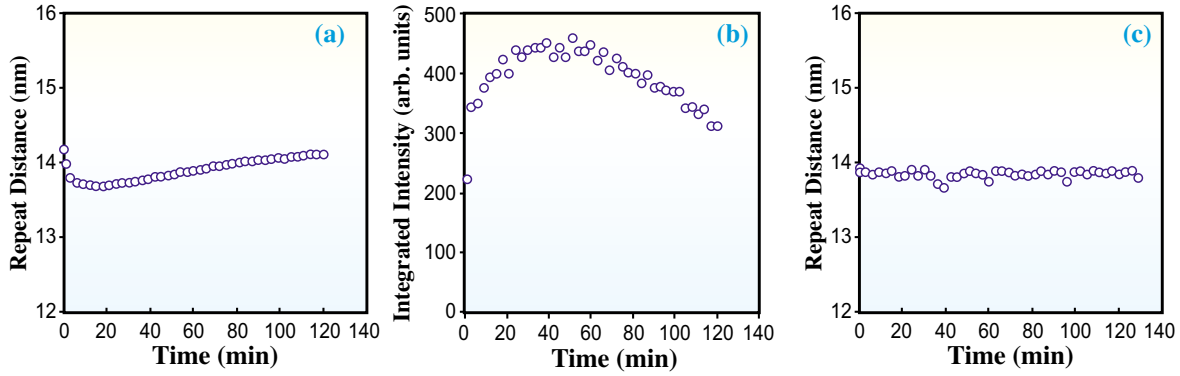

Fig. 2. Repeat distance **(a)** and intensity **(b)** of the third-order X-ray diffraction profiles obtained from the long lamellar structure of the SC treated with 1 wt% SDS. **(c)** Repeat distance of the third-order X-ray diffraction profiles obtained from the long lamellar structure of the SC without SDS treatment. (a) The repeat distance first decreased, then started to increase and finally saturated. (b) The intensity first increased and then decreased.

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