Fibril–vesicle transition and their structures – investigation by microscopy and small-angle scattering

Abstract The formation of fibrous assemblies by fluorinated amphiphiles and the temperature-dependent fibril–vesicle transition were investigated by using microscopy and small-angle scattering. The results were compared with that of fibrous assemblies by nonfluorinated amphiphiles. Sodium (F-octylethyl)nonylmethylene O-6-phosphogluconide (F-Glu) formed hollow tubules in water at room temperature (∼25°C). Tubules transformed into vesicles above 60°C. Similar tubule–vesicle transition for hydrogenated-analog, sodium decynonylmethylene O-6-phosphogluconide (H-Glu), was observed below room temperature. The mixture of [2-(F-octyl)penthyl]dimorpholinophosphate (F8C5DMP) and [2-(F-decyl)ethyl]dimorpholinophosphate (F10C2DMP) in water constructed U- or V-shape assemblies, which changed to vesicles at 60°C.

Key words Vesicle – fibril – cryo-TEM – small-angle X-ray scattering – fluorinated amphiphile

Introduction

It has been known that various types of supramolecular assemblies are constructed in the medium by noncovalent self-organization of small molecules. Many workers reported assembly structures and solution properties [1]. Rod-like micelles which are one group of linearly extended supramolecular assemblies are formed by the hydrophobic interaction between long alkyl chains of amphiphiles. Rod-like micelles are transformed from spherical micelles [2]. In a few cases, rod-like micelles change to vesicles when cinnamic acid is added to a solution of hexadecyl-dimethylamine oxide [3]. The spontaneous transition from polymer-like micelles to vesicles was observed in lecithin–bile salt solutions [4].

Fibrous chains are another group of linear assemblies and were found in gel-like solutions of amphiphiles [5–7], steroids [8], oligobipiridine metal complexes [9], and cyclic peptide [10]. These compounds reveal specific intermolecular interaction such as hydrogen bonding, π–π stacking, and so on, besides hydrophobic interaction. Among supramolecular fibers, helical assemblies are characteristic for molecules with chiral hydrophilic head groups such as amino acids, nucleosides, and sugars [1]. It is also known that some of the fibrous assembly systems display fibril–vesicle transition depending on temperature [11–13].
The formation of supramolecular fibers were mainly confirmed by the transmission electron microscopic (TEM) and the dark-field optical microscopic observation. On the other hand, a few investigations were carried out using techniques of NMR [6], X-ray diffraction [9, 14, 15], small-angle neutron scattering [8, 16, 17], and small-angle X-ray scattering (SAXS) [16, 17].

In this paper, we examined the formation of different kinds of fibrous, linear assemblies from fluorinated amphiphiles by using microscopy and small-angle scattering. We discuss the structure of fibrous chains and the fibril-vesicle transition.

**Experimental section**

Sodium (F-octylethyl)nonylmethylene O-6-phosphogluconoside (F-Glu), sodium decylnonylmethylene O-6-phosphogluconoside (H-Glu), [2-(F-octyl)penthyl]dimorpholinophosphate (F8C5DMP), and [2-(F-decyl)ethyl]dimorpholinophosphate (F10C2DMP) were same samples as previously synthesized and used [18–20].

SAXS was measured at 25 °C by a 6 m point focussing SAXS camera at the High-Intensity X-ray Laboratory in Kyoto University. TEM observation was carried out on a Hitachi H-800 electron microscope. A Hitachi H5001-C cold stage was used for the cryo method. Freeze-fracture replica film was prepared by using a balzers BAF 400 freeze-fracture device.

**Results and discussion**

Figure 1 shows cryo-TEM photographs for aqueous 3% solution of hydrogenated/fluorinated phosphoglucolipid, F-Glu, at various temperatures. F-Glu in water formed very long tubules with hollow inside at room temperature (~25 °C) (Fig. 1a). The diameters were almost uniform. SAXS data (Fig. 2a) fitted to the theoretical curve for a hollow tubule with parameters of external and internal diameters, 280 and 70 Å, respectively. There was a Bragg peak which can be assigned to the reflection from lamellar layers, suggesting the formation of concentric lamellar layers in the cross section of a hollow tubule.

When aqueous F-Glu solution was heated up to more than 60 °C, tubules changed to vesicles (Fig. 1c). The tubule-vesicle transition temperature must be 50–60 °C, because tubules and vesicles coexisted at that temperature (Fig. 1b). It should be noticed that tubules transferred to vesicles through plate (sheet) or tubule expansion. In accord with tubule-vesicle transition, the characteristic Bragg peak in SAXS diminished, as seen in Fig. 2b, indic-