Increased Volume of Hydration around Dextran Molecules by Water Treated with Ultra-Infrared Ray Radiating Ceramics

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The hydration volume around dextran molecules was examined with high and low molecular weight dextrans which were dissolved in tap water and two kinds of water treated with ultra-infrared ray radiating ceramics. The partial specific volumes for the dextran in the ceramics-treated water were higher than that in tap water. The evaporation rates for the ceramics treated water were also higher than that of tap water. The results suggested that the hydration volume around dextran molecules increased because the cluster size of water decreased due to the treatment of the ceramics.

Keywords: dextran; partial specific volumes; evaporation rate; ultra-infrared; functional water

Introduction

We have examined the effects of functional water on dextran, a

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polymer of α-glucose and composed of chains of varying lengths. Recent studies reported that when water was exposed to subtle external energy field, it became functional in various ways and behaved

differently from ordinary water.[1-9]. When water was treated with the ultra-infrared ray radiating ceramics and used for food, the freshness of fruits prolonged, fermentation [10] and the growth rate of plants were promoted [13-14], and water and sugar content in cooked rice increased.[11-12]

Dextran is widely used by food and pharmaceutical industries. In food production, dextran is used mainly as thickening and gelling agents in similar manner to agarose, arginate, and carrageenan. Dextrans of 40,000 Da (T40) and 70,000 Da (T70) are used therapeutically for blood plasma substitutes such as plasma volume expanders and anticoagulants, as well as for blood pressure maintenance agents. In our previous studies in investigating the mechanism of the insolubilization of dextran developed in the injection vial during sterilization and storage, we have revealed that the insolubilization is accompanied by the formation of cross-linked structures among dextran molecules.[15-17]. The findings suggested that the quality of the plasma substitutes and foods using dextran could be controlled by regulating the dispersion of dextran molecules. Since the hydration volume on the surface of the dextran molecules affects their dispersive property, we examined effects of the ceramics-treated water on the dextran molecules by measuring the density of water samples and obtaining partial specific volume of dextran.

We also examined the characteristic properties of the ceramics-treated waters by measuring their evaporation rates and their relationships to the dextran's dispersive property. A possibility of regulating the dispersion of dextran by the ceramics-treated water is discussed.

Materials and methods

1. Preparation of ceramics-treated water and dextran solution

Two kinds of ceramic-treated water were prepared by flowing tap water (Hirakata City Waterworks, Osaka) through two stainless steel cylinders, each of which was packed closed with two kinds of ultra-infrared radiating ceramic-balls [18] (Shin-ei Sangyo Co. Ltd., Osaka, Japan) as described in Table 1. The flowing pressure and rate were set at 1.96×10^5 Pa and 8×10^{-3} m^3/min, respectively. The same tap water was used as a control.

The two ceramics-treated water, A and B, as well as the tap water were kept at 25°C. One g of dextran of 70,000 Da (T70 Pharmacia Lot No.279504) or that of 500,000 Da (T500 Pharmacia Lot No.MD01805) was dissolved in the ceramics-treated water A, B, and the tap water to 50ml in volume. The three water and six prepared dextran solution samples were incubated at 25 $^\circ$C for 2h and used in the following experiments.

2. Measurements

(1) Density measurement of the samples

Table1 Description of water sample

Water Samples	Description
Control water	Tap water of Hirakata City Water System, Osaka, Japan
Ceramics-treated Water A	Prepared by having the tap water flow through once a stainless steel cylinder of 66 cm in length and inner cross section area of 164cm^2, which was packed with 248 ceramics balls (No.2 ceramics ball, medium size, Shin-ei Sangyo, Co. Ltd., Osaka, Japan).
Ceramics-treated Water B	Prepared by having the tap water flow through once of a stainless steel cylinder of 47 cm in length and inner cross section area of 32cm^2, which was packed with 10 ceramics balls (No.2 ceramics ball, medium size, Shin-ei Sangyo, Co. Ltd., Osaka, Japan)

The mass for each of the three water samples as well as the six prepared dextran solution samples was measured by using Gay-Lussac's pycnometer. The temperature of the samples was also measured to obtain their density.

(2) Estimation of partial specific volume

Partial specific volume of dextran solution (V) was calculated with the following formula,

$$V = (1/\rho_0) \times \{1-(\rho-\rho_0)/c\}$$

c=2.00x10g/ml,

where the values ρ_0, ρ, and c are density of water, density of dextran solution, and concentration of dextran solution, respectively.

(3) Measurement of evaporation

The amount of evaporated water for each of the nine samples was measured using the evaporation rate measuring system developed by Shin-ei Sangyo Co. Ltd., Osaka, Japan. (Fig.1). Since the evaporation rate is susceptible to temperature, the measurement was carried out in a double-chamber system under a strict temperature control. The temperature of the inner chamber was stabilized by regulating that of outer chamber. The humidity was also controlled by the same manner. An analytical electronic balance was placed in the inner chamber under the controlled temperature and humidity, and a water-absorbing LiCl plate was placed on the balance. A cylindrical container of 20 cm in diameter was placed immediately next to the balance. The measurements for the nine samples of 2L each were

Fig.1 A photograph of the evaporation rate measuring device developed by Shin-ei Sangyo, Co. Ltd, Osaka, Japan.
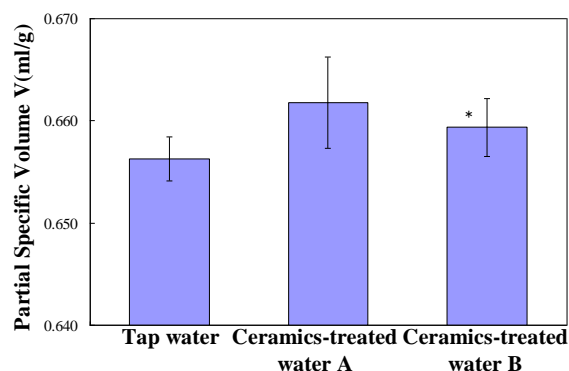
Fig.2 The partial specific volume (PSV) of T70 dextran dissolved in the ceramics treated water A and B, and control water at 25℃. The bar graphs depict the average PSV ± standard deviation (n=5) for the three T70 solutions. * indicates a significant value (p<0.05) compared to tap water.

carried out at 25 $^{\circ}$C and 30 % humidity. The temperature of sample was equilibrated to that of the inner chamber. The quantity of the water evaporation was recorded every minute for 60 minutes as the amount of water absorbed by the LiCl plate.

(4) Statistical analysis

The data for the evaporation rate for each of the water samples were collected and their means and standard deviations were obtained. T-test was performed to assess the statistical significance, and p<0.05 was considered significant.

Results and Discussion

1. Partial specific volume (PSV) of dextran solution

No density difference was observed among the water samples at 25 $^{\circ}$C. After measuring the density of the six dextran solutions, their partial specific volume (PSV), volume (ml) per 1g of dextran, was calculated. The obtained PSVs for T70 and T500 dextran solutions

were summarized in Figures 2 and 3, respectively. In both T70 and T500 cases, the PSVs for the dextran solution prepared with the ceramics-treated water A and B were larger than that with the tap water. For the T70 case, the PSV in the water B was significantly larger than in the control tap water. For the T500 dextran case PSV in the water B was slightly larger than that in the others.

2. Evaporation rate

Electric conductivity increases if trace elements are eluted to water from ceramics as are from maifan stone. Examining the three water samples, we found no differences in oxidation-reduction potential and electric conductivity[11]. No elements were eluted to the water from the ceramics, since the element analysis did not detect any differences in element contents among the three water samples (data not shown).

Although it is unclear how the ultra-infrared radiating ceramics affects the structure of water, it has been suggested that the ultra-infrared ray released from the ceramics may play an important role on changing the cluster size of water. The hydrogen-bond strength of water cluster is approximately 21J/mol and the wavelength of electromagnetic wave corresponding to this energy is 5μm[10]. Since the both ceramics used in this experiment have the maximum emission wavelength whose corresponding energy is higher than
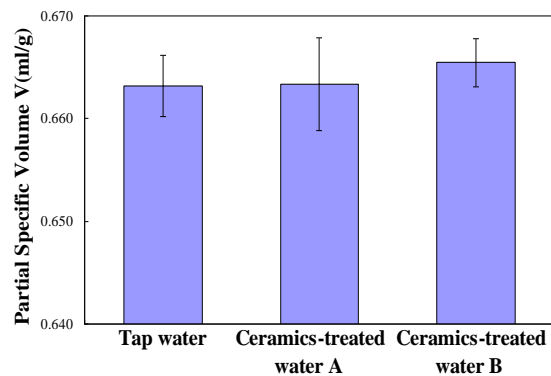

Fig.3 The partial specific volume (PSV) of T500 dextran dissolved in the ceramics treated waters A and B, and control water at 25℃. The bar graphs depict the average PSV $\pm$ standard deviation (n=5) for the three T500 solutions.

21J/mol, the generated ultra-infrared rays from the ceramics may have cut the hydrogen bonding between water molecules and the cluster size of water becomes smaller.

The evaporation of water occurs when the surface of the liquid is exposed, allowing molecules to escape and to form vapor. As the cluster size of water becomes small, the intermolecular forces become weak, and water molecules escape from the surface easily. As a result, the evaporation rate is accelerated. Since the measuring evaporation rate is a nondestructive method for indirectly measuring the size of water cluster, this method can be applied for evaluating functional water.

Figure 4a shows the evaporation rates for the three water samples. The vertical and horizontal axes show the amount of water
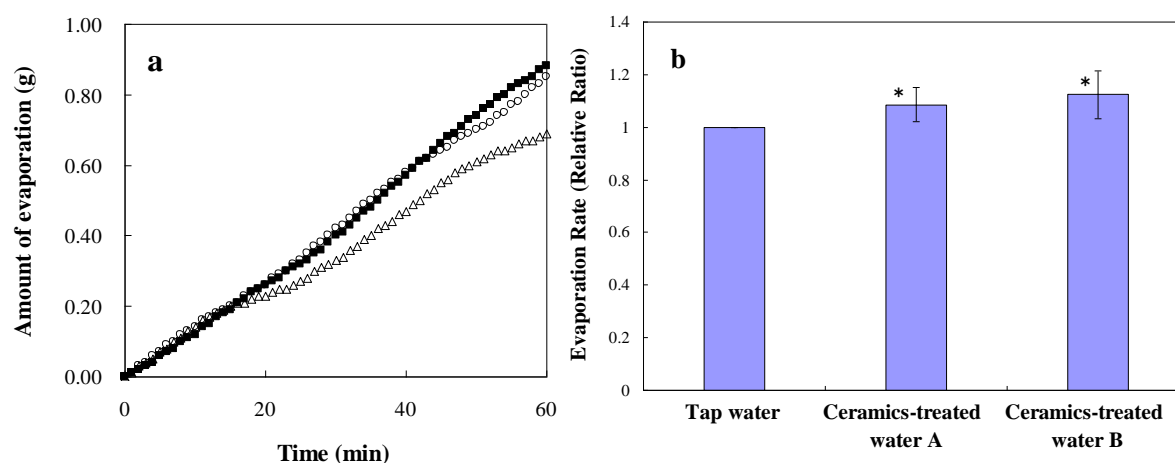

Fig.4a The volume of evaporated water and the time were plotted for the three water samples, tap water (△), ceramics-treated water A (○), and ceramics-treated water B (■). 4b The relative ratios of the average evaporation rate $\pm$ standard deviation (n=5) for the ceramics-treated water A, ceramics-treated water B by placing that for the control water as 1. * indicates a significant value (p<0.05) compared to tap water.

evaporated and the measurement time respectively, and the gradient indicates the evaporation rate. The initial gradient indicates how readily water molecules evaporate, which should reflect the size of water clusters. As shown in Fig.4a, the amount of evaporated water was larger for the both ceramics-treated water than for the control. In order to make the relationship between the evaporation rate and the water cluster size clear, we obtained the relative ratio of the evaporation rate of the three water samples for one hour period by placing that of the control as 1. As depicted in Fig. 4b, the relative ratios for the ceramics-treated water A and B were higher than that for the control, which suggests that the treatment of water with the ceramics induces the reduction of the cluster sizes. We have expected that the density of water changes as the cluster size changes. However, the pycnometer did not detect any differences in density among the water samples. Further experiments are needed for detecting and measuring the water density changes by using methods more sensitive than the pycnometer.
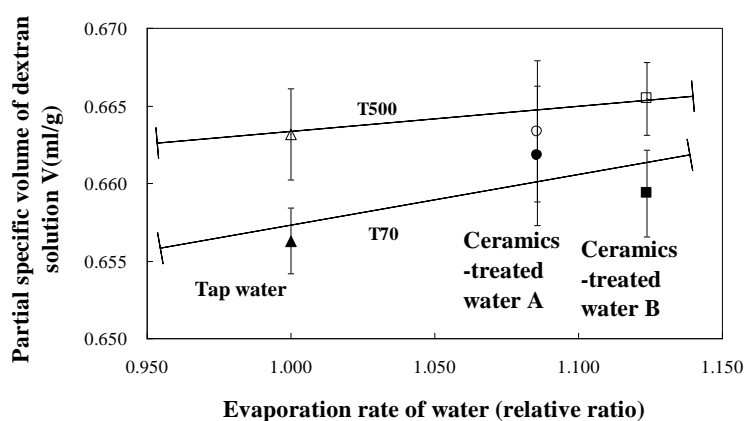

Fig.5 The least square method was applied to examine the relationship between the means of partial specific volume for the T70 and T500 dextran solutions and the evaporation rates of the water samples. A positive correlation was obtained for T70 dextran solution.

3. Correlation between partial specific volume (PSV) of dextran solutions and the rate of water evaporation

The least squares method was applied to examine the relationship between the means of partial specific volume (PSV) for the T70 and T500 dextran solution and their evaporation rates. As Fig. 5 shows a positive correlation between the PVS and evaporation rate for the PVS of dextran T70 (MW. 70,000), and indicates that the cluster size becomes small as the PSV increases. For the dextran T500 (MW. 500,000) solution, a similar tendency was recognized; however, it did not show a clear positive correlation.

Small angle X-ray scattering studies have shown that dextran of relatively small molecule in solution such as T70 has random coil structures[15-17], where water molecules pass between the dextran molecules freely. In such "free-drainage" structure, the water molecules are attached to hydroxyl group of sugar chains of dextran by hydrogen bonding, and form a hydration layer. When the water cluster size is small, long-range interaction force among the water molecules in the hydration layer is relatively strong. Consequently, the layer around the dextran molecules is thick and dense. If the cluster size is large, such as tap water, the water molecules form hexagonal structure with a large cavity in the center. Since the water molecules in such structure attach to each other by weak short-range interaction force, the hydration layer is sparse and thin. The correlation between the PSV and evaporation rate is obtained because of the formation of the hydration layer attributable to the characteristics of the dextran T70 structure and size of water cluster.

The strong interaction force between the polysaccharide

segments in T500 dextran forms microgel structure, where water molecules cannot pass freely through the dextran molecules [19]. In this "non-free drainage" structure, tap water having large cluster size can not enter the space between the segments. On the other hand, the cluster size of the ceramics-treated water B is small enough to enter the space, which may cause the thickness of the hydration layer to increase. It is suggested that the partial specific volume (PSV) increases because the ceramics-treated water with small cluster size forms a thick hydration layer around dextran molecules. When the ceramics-treated water makes such thick hydration layer around the dextran molecules, they become stable and their molecular associations are inhibited. In other words, aggregation of dextran in solution can be prevented when the ceramics-treated water is used as solvent.

Our results suggest that the ceramics-treated water could be used to control the dispersion of dextran in solution. This function can be applied for food production as it is particularly useful for obtaining stable thickening agents over time. Furthermore, the thick hydration layer may give smooth texture on the palate. In our laboratory, we have observed that the dispersion stability of brown sugar in ceramics-treated water is more stable than that in tap water and the level of water retention of soy milk prepared with ceramics-treated water is higher than that with tap water (data not shown). The ceramics-treated water also has such potential pharmaceutical application as for intravenous injection preparations using dextran since it could prevent precipitation of dextran.

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