Elucidation of the mechanism of strength enhancement of collagen gels induced by silica nanoparticles

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Abstract

Collagen hydrogels are promising materials for biomedical applications because collagen is a major component of the extracellular matrix, and the mechanical properties of collagen networks affect cellular behavior. Therefore, controlling gelation and mechanical properties is important for the development of bioadaptive materials. Silica nanoparticles have been reported to reinforce collagen gels formed by neutralizing aqueous collagen solutions.[1] However, the relationship between the microscopic structure of collagen–silica systems and their macroscopic mechanical properties remains unclear.

In this study, small-angle neutron scattering (SANS) was used to investigate structural changes in collagen gels induced by silica nanoparticles. Type-I collagen solutions were prepared in deuterated solvent, and SANS measurements were performed before and after neutralization-induced gelation for samples with and without silica nanoparticles. The scattering profiles were analyzed to evaluate changes in the collagen network structure caused by gelation and silica addition. The SANS results were compared with rheological data to clarify how silica nanoparticles modify the microscopic structure and mechanical properties of collagen gels. The obtained structural information is expected to support the control of collagen-gel properties and the design of collagen-based extracellular-matrix materials.

Method

Acidic type-I collagen solution (0.3 wt%) was neutralized by adding phosphate-buffered saline to prepare collagen gel samples. Collagen–silica nanocomposite (NC) gels containing dispersed silica nanoparticles were also prepared. SANS measurements were performed for samples with different solvent D_2O fractions over a q-range of 0.0024–0.35 Å^{-1}.

Result

Figure 1 shows the scattering profiles obtained by SANS for the collagen solution and collagen–silica nanocomposite gel. For the collagen solution, the scattering intensity increased after neutralization-induced gelation, particularly in the low-q region. This increase is attributed to the formation of a three-dimensional collagen network and the accompanying increase in structural heterogeneity on the nanometer-to-micrometer scale. The result indicates that gelation produces larger spatial inhomogeneities in the collagen density than those present in the sol state. In the collagen–silica nanocomposite gel, an increase in the scattering intensity, $I(q)$, was observed at $q = 0.02 - 0.05$ Å^{-1}, originating from the form factor, $P(q)$, of the silica nanoparticles. To describe the obtained scattering profiles in greater detail, partial scattering functions will be calculated by applying singular value decomposition analysis to scattering data obtained from samples with different solvent H/D ratios. This analysis will be used to extract structural information on the collagen network and silica nanoparticles separately.

References

[1] M. F. Desimone *et al., Acta Biomater*. **6**, 3998 (2010).

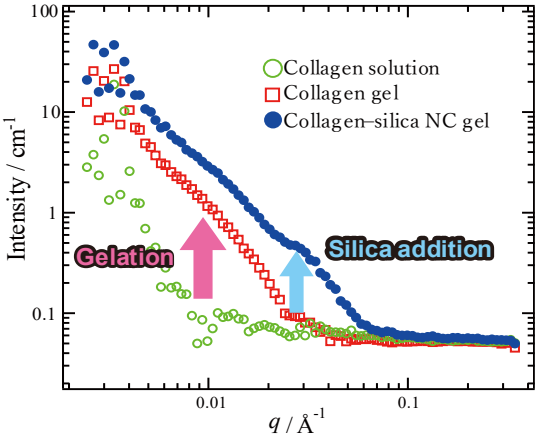

Fig. 1 SANS profiles of collagen solution and gels.