Observations of Multiscale, Stress-Induced Changes of Collagen Orientation in Tendon by Polarized Raman Spectroscopy

Abstract

Collagen is a versatile structural molecule in nature and is used as a building block in many highly organized tissues, such as bone, skin, and cornea. The functionality and performance of these tissues are controlled by their hierarchical organization ranging from the molecular up to macroscopic length scales. In the present study, polarized Raman microspectroscopic and imaging analyses were used to elucidate collagen fibril orientation at various levels of structure in native rat tail tendon under mechanical load. In situ humidity-controlled uniaxial tensile tests have been performed concurrently with Raman confocal microscopy to evaluate strain-induced chemical and structural changes of collagen in tendon. The methodology is based on the sensitivity of specific Raman scattering bands (associated with distinct molecular vibrations, such as the amide I) to the orientation and the polarization direction of the incident laser light. Our results, based on the changing intensity of Raman lines as a function of orientation and polarization, support a model where the crimp and gap regions of collagen hierarchical structure are straightened at the tissue and molecular level, respectively. However, the lack of measurable changes in Raman peak positions throughout the whole range of strains investigated indicates that no significant changes of the collagen backbone occurs with tensing and suggests that deformation is rather redistributed through other levels of the hierarchical structure.