Extensional Flow of Hyaluronic Acid Solutions in an Optimized Microfluidic Cross-Slot Device

Simon J. Haward

Micro/Bio/Nanofluidics Unit, Okinawa Institute of Science and Technology, Onna, Okinawa 904-0495, Japan

In this talk I will describe the development of a microfluidic device designed to generate a close approximation to ideal planar elongational flow and its application to study the extensional rheological properties of hyaluronic acid (HA) solutions representative of the synovial fluid (SF) found in the knee joint [1,2]. The microfluidic Optimized-Shape Cross-slot Extensional Rheometer (OSCER) [1] has two opposing inlets and two opposing outlets and has a numerically optimized shape that generates hyperbolic streamlines around a central stagnation point. The resulting planar elongational flow field is compressive along the inlet channels, extensional along the outlet channels, and can be considered representative of the flow occurring in knee joints during running or jumping movements, in which the SF found in the joint cavity is subjected to high extensional and compressional deformation rates. A range of techniques is employed to study the flow of high molecular weight HA solutions in the OSCER device at concentrations close to those typically found in physiological SF. For flows above a critical rate, full-field birefringence microscopy measurements demonstrate a high degree of localized macromolecular orientation along streamlines passing close to the stagnation point. Micro-particle image velocimetry is used to independently quantify the flow kinematics in the OSCER device. In addition, measurements of the bulk pressure drop across the microfluidic device are used to assess the non-Newtonian increases in apparent extensional viscosities of the HA solutions as the deformation rate is increased. The large limiting values of the dimensionless *Trouton ratio* (in excess of 100), demonstrate that these fluids are highly extensional-thickening, providing a clear mechanism for the load-dampening properties of SF. The results also indicate the potential for utilizing the OSCER in screening of physiological SF samples, which could lead to improved understanding of the progression of joint disease and/or improved formulation of prosthetic fluids for palliative care of arthritis sufferers.

[1] S.J. Haward, M.S.N. Oliveira, M.A. Alves & G.H. McKinley (2012) *Phys. Rev. Lett.*, **109**: 128301.
[2] S.J. Haward, A. Jaishankar, M.S.N. Oliveira, M.A. Alves & G.H. McKinley (2013) *Biomicrofluidics*, **7**: 044108.