Stretching of Single DNA Molecules under Pressure-Driven Flow in Straight and Curved Microfluidic Channels

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KEY WORDS: Microfluidics, DNA mapping, fluid dynamics, Brownian motion.

Microfluidic channels are investigated here with a view to unravel and deliver long genomic DNA strands (>20μm) into channels for subsequent optical interrogation. Previous studies have focused on devices where strands are stretched under sudden shear and elongational microflows, but unfortunately there is a potential for strand fragmentation[1]. We investigate differently shaped microchannels to deliver intact strands for subsequent genome mapping.

This unravelling and stretching of DNA is based on the shear forces present in a pressure-driven laminar flow inside a microchannel of dimensions comparable to the length of the DNA. However, diffusion induced by Brownian motion tends to accumulate DNA in the region of maximum flow velocity at the centre of the channel where shear forces vanish and DNA strands start to coil up again. We have found experimentally that this can be mitigated by employing curved microfluidic channels[2]. In particular there is evidence that serpentine-shaped channels deliver more fully extended DNA strands than simple straight channels.

To understand the mechanism behind this improvement we perform numerical simulations combining a computational fluid dynamics (CFD) model of the microchannel with Brownian dynamics of a coarse-grain model of λ-DNA molecules[3], see Fig. 1(a). Comparing the simulations of a serpentine channel with those of a straight channel supports the experimentally found improvement of DNA stretching in the former, Fig. 1(b), with 17% of DNA molecules stretched to >15 μm length (>75% of maximum extension) compared to 5% in the case of a straight channel. A detailed analysis of the DNA dynamics reveals that the elastic molecular forces opposing the stretching of the molecule are pulling the DNA out of the central flow line towards the inside of a microchannel bend and thus into regions of larger shear forces. This gives rise to larger average DNA extension but it can also be seen in a modified spatial distribution of the molecules over the channel cross section at the output.

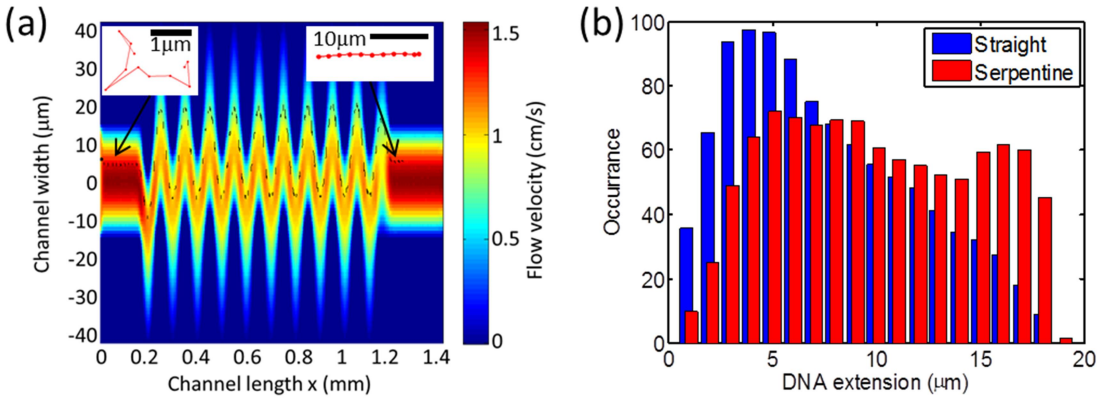

Fig.1. (a) CFD model of a serpentine microfluidic channel with a sample simulation of DNA dynamics. Insets show the shape of DNA before and after the channel. (b) Distribution of single λ-DNA molecule extension after 1.4 mm straight and serpentine channels (1000 simulations each).

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