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RESEARCH PAPER

Rapid and accurate generation of various concentration gradients using polydimethylsiloxane-sealed hydrogel device

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Abstract We report a microfluidic device that can rapidly and accurately generate various concentration gradients in a controllable manner for the chemotaxis study of motile bacterial cells by integrating hydrogel into polydimethylsiloxane (PDMS) microchannels. We performed numerical simulations for both the PDMS-sealed hydrogel hybrid device and a representative conventional hydrogel-based device to theoretically compare their characteristics. In addition, we experimentally demonstrated that the PDMS-sealed hydrogel device not only produces various linear and nonlinear concentration gradients without flow-induced shear stresses on motile bacterial cells but also exhibits remarkable advantages over conventional hydrogel-based devices. For example, the PDMS-sealed hydrogel device can be used for fast and accurate generation of various concentration gradients, prevents dehydration of hydrogel and evaporation of solutions, directs diffusion of chemicals such as chemoattractants, exhibits long-term durability, and is easy to handle. Because the hydrogel used is biocompatible and arbitrary concentration profiles can be easily designed and produced on a chip, we believe that not only the PDMS-sealed hydrogel fabrication method but also the versatile concentration gradient generation device can be used for various studies on interaction between chemicals and cells including bacterial chemotaxis assays.

Keywords Microfluidics · Hydrogel · Polydimethylsiloxane · Concentration gradient · Chemotaxis

1 Introduction

Bacterial chemotaxis is a model that clarifies how cells and microorganisms sense and respond to concentration gradients in chemical environments (Adler 1966; Ahmed et al. 2010b). Apart from the studies on the chemotaxis of surface-adherent cells such as neutrophils (Jeon et al. 2002; Sahai et al. 2011), it is more challenging to study the chemotaxis of motile bacterial cells because they are highly susceptible to convection flow. As a result, direct application of convection flow-based microfluidic devices to study the chemotaxis of motile bacteria is limited and diffusion-based devices have conventionally been preferred to study bacterial chemotaxis (Kim and Kim 2010; Cheng et al. 2007; Ahmed et al. 2010a). The diffusion of small chemoattractant molecules is controlled by using nanoporous, biocompatible materials such as agarose hydrogel (Cheng et al. 2007; Ahmed et al. 2010a; Kim and Kim 2010; Si et al. 2012), polyethylene, polycarbonate, nitrocellulose membranes (Chueh et al. 2007; Kim et al. 2009; Diao et al. 2006), and self-assembled nanoparticles (Choi et al. 2012). However, using such materials is an obstacle to producing various concentration profiles for different chemoattractants. Although laminar flow-based devices have previously been used to quickly generate and tune concentration gradients (Kim et al. 2011; Jeon et al. 2002;

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