Colloids and Surfaces B: Biointerfaces xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Colloids and Surfaces B: Biointerfaces

journal homepage: www.elsevier.com/locate/colsurfb

Precise manipulation of cell behaviors on surfaces for construction of tissue/organs

Wenfu Zheng, Xingyu Jiang*

Beijing Engineering Research Center for BioNanotechnology & CAS Key Laboratory for Biological Effects of Nanomaterials and Nanosafety, National Center for NanoScience and Technology, 11 BeiYiTiao, ZhongGuanCun, Beijing 100190, PR China

ARTICLE INFO

Article history:
Received 15 May 2014
Received in revised form 17 August 2014
Accepted 20 August 2014
Available online xxx

Keywords:
Microfluidics
Cell
Soft lithography
Surface
Chip

ABSTRACT

The use of micro/nanotechnology has become an indispensable strategy to manipulating cell microenvironments. By employing key elements of soft lithographical technologies including self-assembled monolayers (SAMs), microcontact printing (μCP), and microfluidic pattering (μFP) and a number of switchable surfaces such as electrochemical active, photosensitive, and thermosensitive surfaces, scientists can control the adhesion, proliferation, migration and differentiation of cells. By combining essential *in vivo* conditions, various physical or pathological processes such as cell–cell interaction in wound healing and tumor metastasis could be studied on well-defined surfaces and interfaces. By integrating key elements in live tissues, *in vitro* models mimicking basic structure and function of vital organs such as lung, heart, blood vessel, liver, kidney, and brain have been developed and greatly increased our knowledge of these important life processes. In this review, we will focus on the recent development of these interfacial methods and their application in fundamental biology research.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Attaching to extracellular matrix (ECM) is a prerequisite for most mammalian cells to survive, proliferate, differentiate, and carry out their functions. The ECM, an insoluble scaffold largely comprised of proteins and other biomolecules, provides a wide range of physical and chemical cues to cells. Physical cues such as topography and stiffness in the ECM provide the mechanical support and transmit external stimulations to the cells. Chemical cues such as hormones, cytokines, ionic strength, and pH values are present in ECM, providing multiple chemical stimulations for the cells. *In vivo*, physical and chemical microenvironments synergistically regulate cell behavior.

With the development of cell biology and regenerative medicine, the need for precise control of cell behaviors and construction of *in vitro* tissues has increased. Soft lithography, a set of techniques for patterning surfaces, provides convenient, effective, and low-cost means to meet the needs. The key elements of soft lithography include elastomaric stamps, masks, and prototyping. Soft lithographical techniques, such as self-assembled monolayers (SAMs), microcontact printing (μCP), and microfluidic pattering (μFP) have been widely used to pattern a variety of different substrates and have been extensively reviewed [1]. SAMs are 1–3 nm-thick nanostructures formed by regularly assembled organics by the adsorption of molecular constituents onto a surface. The molecules that form SAMs usually have a functional headgroup with a specific affinity for a substrate. The most extensively studied class of SAMs is derived from the adsorption of alkanethiols on gold, silver, copper, palladium, and platinum [2]. In particular, SAMs of alkanethiolates on gold are currently the most widely studied class of model organic surfaces that permit control over interfacial structure and properties. μCP is a technique that uses topographic patterns on the surface of an elastomeric PDMS stamp to form patterns on the surfaces of various substrates. The stamp inked with a solution containing the patterning component (thiols, activated silanes, and various ligands) can be dried and brought into conformal contact with the substrate surface to transfer the components to the substrate in the regions of contacts with high spatial definition. μFP is a technique that uses microfluidic channels to restrict the flow of fluids to desired regions to form patterns on various substrates. A variety of patterning components (ligands, proteins, or cells) and substrates (gold, glass, polystyrene) could be used in μFP.

In recent years, a number of studies combining soft lithography technologies and basic biological issues emerged and have become useful for biological and medical research. This review will first discuss a variety of novel methods to control cell adhesion, migration, and differentiation on surfaces; these methods include electrochemical and photo-/thermo-responsive surfaces that result

* Corresponding author. Tel.: +86 1082545558.
E-mail address: xingyujiang@nanoctr.cn (X. Jiang).

http://dx.doi.org/10.1016/j.colsurfb.2014.08.026
0927-7765/© 2014 Elsevier B.V. All rights reserved.

Please cite this article in press as: W. Zheng, X. Jiang, Precise manipulation of cell behaviors on surfaces for construction of tissue/organs, Colloids Surf. B: Biointerfaces (2014), http://dx.doi.org/10.1016/j.colsurfb.2014.08.026

in different chemistry, topography and stiffness. The following part will introduce the studies of cell–cell interactions in wound healing and tumor metastasis using microfluidic techniques. The last part will introduce the newly developed microfluidic models simulating organ-level functions of blood vessel, lung, heart, liver, kidney, and brain.

2. Control cell adhesion on surfaces

2.1. Patterning cells with inert and adsorptive surfaces

Identification and design of new surfaces that can resist nonspecific adsorption of protein is a central goal in new biomaterial development and basic biological research. Inert surfaces provide the background necessary for spatially restricted protein adsorption or for preparing surfaces that only bind specific proteins, and are used in patterning proteins as well as cells. Poly (ethylene glycol) (PEG) is the most common molecule to result in inert surfaces, and a variety of strategies for tailoring surfaces with PEG have been developed [3]. SAMs terminated in oligo (ethylene glycol) (EGn, $n > 2$), resist the adsorption from solution of all known proteins and their mixtures [4]. SAMs terminated in methyl groups is hydrophobic and adsorptive for proteins. The combination of inert and adsorptive surfaces with soft lithographic techniques provides the basis for patterning of proteins and cells in most studies [2].

Using geometrical confined adsorptive patterns surrounding with inert surface based on thiol SAMs on gold surface, Chen et al. [5] controlled the endothelial cells to specific-shaped regions and studied the relationship between the cell live/death and cell shapes. The dynamic process of cell confining and releasing from patterns based on thiol-SAMs-on-gold-surface were realized by electrochemistry [6]. On the PEG based inert/adsorptive SAM system on gold surface, we studied the directional migration of cell on confined teardrop shaped pattern [7]. Kushiro et al. [8] further revealed that the gap size, teardrop asymmetry and the relative positioning of teardrop are all essential features influencing the directional cell migration. To achieve reversible control of cell adhesion, Yoon et al. fabricated gold electrode arrays on glass surface and functionalized gold electrodes with arginylglycylaspartic acid (RGD) terminated thiol to induce cell adhesion, whereas treated the glass substrate with PEG to prevent cell adhesion. By switching the electrodes to desorb the gold-thiol SAM, the attached cells on the electrodes could be detached [9].

Besides thiol SAMs, other molecules have been used to pattern cells. Fan et al. precoated pluronic copolymers on a dielectric surface with microelectrode arrays. By selectively switching on microelectrode, the perfusing of fibronectin solution could produce protein patterns on the surface which could reveal desired cell patterns on the surface [10]. By microcontact printing (μCP) an amphiphilic, protein resisting comb polymer on glass following the incubation of the surface with fibronectin solution, Hyun et al. [11] fabricated mammalian cell patterns which could be maintained alive for more than 25 days [11]. To direct control over feature height of micropatterns, Khademhosseini et al. [12] synthesized a PEG based polymer poly ((3-trimethoxysilyl)-propyl methacrylate-ran-poly (ethylene glycol) methyl ether methacrylate (poly(TMSMA-γ-PEGMA)) and generated micropatterns on silicon oxide surface by using capillary force lithography. The patterns of cells were formed driven by patterned adhesive fibronectin and repulsive polymeric monolayers of poly(TMSMA-γ-PEGMA). Apart from gold, glass, and silicon surface, soft surfaces such as hydrogels have been utilized to pattern cells. Cao et al. [13] generated a series of microarrays of cell-adhesive RGD on a persistent non-fouling PEG hydrogel and researched the effects of spreading areas and aspect ratios of single cells on dedifferentiation of chondrocytes. Engineered cardiac tissues were cultured on the micropatterns generated on gelatin hydrogels by μCP of fibronectin [14]. Based on inert/adsorptive surface, various multiple cell–cell interactions [15–18] were systematically studied. So, the inert/and adsorptive surfaces provide a convenient tool for cell biology research.

2.2. Manipulation of cell adhesion on surfaces

Cells are major constituents of living organisms. Most cells require adhesion to substrates in order to carry out biological activities. Understanding and exploiting cell adhesion are an active area in biological research [19]. Various model surfaces have been developed to control cell adhesion [20].

Compared with conventional "static" artificial surfaces, switchable surfaces will become possible to regulate the cellular environment in a spatiotemporally controlled manner and to address cellular dynamic activity, such as cell migration and signaling transduction, in response to matrix remodeling. Here, we will review switchable surfaces for cell biology based on electrochemical, photoresponsive, and thermal properties of surfaces.

2.2.1. Electrochemical active surfaces

The stability of SAMs on gold surface varies at different range of electrochemical potentials. The potential at which the desorption of the SAMs occurs depends on the length of the alkyl chain, the degree of ordering and the number of intermolecular interactions within the SAMs, and the crystallinity of the gold substrate [21]. We have developed a method that can release patterned cells on cell adhering SAMs for free migration by applying a cathodic voltage on gold surface [6]. Furthermore, by electrochemical desorption of SAMs in localized areas defined by a microfluidic system [15,16], we selectively released patterned multiple types of cells on the substrate and simulated complex cell–cell interactions *in vivo*: (1) those between two types of cells that are both immobilized and confined to isolated areas; (2) those between one cell type that is immobile and another that moves freely; and (3) those between two or more types of cells that are both moving freely. This technique has the capability to pattern different types of cells with precisely controlled distances while allowing the free exchange of soluble molecules, making co-culturing of different types of cells more accessible to biologists (Fig. 1).

The above methods provide the means to release attached cells, but, in some cases, precise immobilization of cells from solution onto the surface is needed. Wittstock et al. described a strategy to manipulate the cell-adhesive property of an OEG terminated SAM substrate using ultramicroelectrodes. The OEG SAMs can rapidly switch to cell adhesive by exposure to Br_2, which can be electrogenerated from Br^- in aqueous solution. By using this method, cellular micropatterns could be fabricated *in situ* [22]. Nishizawa and colleagues reported a strategy to create a patterned surface within a microfluidic channel by locally generating hypobromous acid at a microelectrode, the heparin-coated channel surface rapidly switches from antibiofouling to protein-adhering, enabling site-specific immobilization of proteins and cells under physiological conditions. In biological studies, repeated desorption and reattachment of cells on a substrate is required. Electrical potentials that stimulate a geometry change in the surface-bound molecules have been shown to facilitate rapid and reversible switching. Yeo et al. [23] developed a SAM that can convert O-silyl hydroquinone to benzoquinone and subsequently hydroquinone using oxidization and reduction reactions successively initiated by electrical potential. During this process, the RGD peptide present on the O-silyl hydroquinone can be selectively released to release adhered cells from the substrate. Benzoquinone group, which undergoes a selective immobilization reaction with a diene-tagged peptide, can be reduced to the hydroquinone, which prevents

Please cite this article in press as: W. Zheng, X. Jiang, Precise manipulation of cell behaviors on surfaces for construction of tissue/organs, Colloids Surf. B: Biointerfaces (2014), http://dx.doi.org/10.1016/j.colsurfb.2014.08.026

Download English Version:

https://daneshyari.com/en/article/599454

Download Persian Version:

https://daneshyari.com/article/599454

Daneshyari.com