Microfluidic devices for biomedical applications
Microfluidic devices for biomedical applications

Edited by
Xiujun (James) Li
and Yu Zhou
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Note: The order of editors’ names does not denote their importance in producing this book.
Preface

Biomedical applications ranging from drug discovery and delivery and disease diagnosis to point of care (POC) devices and tissue engineering have attracted increasing attention since the last few decades. Biomedical engineering, closely related to biomedical applications, has only recently emerged as its own discipline. Conventional biomedical techniques however often face increasing challenges in different biomedical applications, such as high cost, slow diagnosis, expensive instrumentation, low drug delivery efficiency, and high failure rates in drug discovery due to the discrepancy between 2D cell-based assays and living tissues. Additionally, many cases of global diseases (e.g. malaria, tuberculosis, or TB, meningitis and hepatitis B) happen in high-poverty areas, such as rural areas and developing nations which often cannot afford expensive and high-precision instruments. For instance, according to World Health Organization (WHO) data in 2012, 'one million cases of bacterial meningitis are estimated to occur and 200 000 of these die annually'. All these pose great challenges to conventional biomedical techniques.

Microfluidic or lab-on-a-chip (LOC) devices emerged in the 1990s and have grown explosively in the last two decades due to their inherent advantages associated with miniaturization, integration, parallelization, as well as portability and automation, including low consumption of reagents and samples, rapid analysis, cost-effectiveness, high efficiency and less human interference during operation. Microfluidics offers great potential in addressing those challenges in biomedical applications. Countless microfluidic systems have been developed for high-throughput genetic analysis, single-cell analysis, proteomics, low-cost diagnosis, pathogen detection, controlled-drug release, and tissue engineering. After a concise introduction of the fundamentals of microfluidic technologies, this book highlights current cutting-edge research of microfluidic devices or LOC platforms in biomedical applications.

Part I mainly aims to introduce the fundamentals of microfluidic technologies. Suitability of device construction materials and methods is highly critical to the success of different biomedical applications. Chapter 1 is dedicated to introduce a variety of widely used materials in microfluidic devices and their corresponding fabrication methods. Because stable and well-characterized surfaces are essential to achieve desired performance in some
biomedical applications, Chapter 2 provides an overview of strategies used to accomplish surface coating. Covalent and adsorptive coating strategies are included. Actuators are responsible for sophisticated manipulation of fluids and particles in microfluidic systems and have been proved to be of significant importance in the successful implement of microfluidic operations. Chapter 3 summarizes major actuation principles used in medical devices, and concentrates on two mechanisms, namely, electrokinesis and acoustics. Digital microfluidics has recently emerged as a popular approach to transport individual droplets on an array of patterned electrodes. Therefore, Chapter 4 discusses the most recent development of this technology with particular attention to actuation and sensing scalability.

Part II focuses on applications of microfluidic devices for drug delivery and discovery. The applications of microfluidics technology in drug delivery and discovery have experienced a sustainable growth in the past two decades. Microfluidic devices have become an increasingly important tool to improve the efficiency of drug delivery and reduce side effects of treatment. Chapter 5 provides an overview of controlled drug delivery with various microfluidic devices and triggering mechanisms. In particular, Chapter 6 is dedicated to the study of the transdermal delivery of drug molecules and monitoring biological fluids using microfabricated needles and provides an overview of recent progress on the microneedle technology. The last chapter in Part II, Chapter 7, presents the roles of microfluidic chips in current drug discovery and in high-throughput screening, identification of drug targets and preclinical testing. Potential applications of microfluidic devices in chemical analysis as well as analysis of metabolites in blood for studying pathology are also discussed herein.

The cell is the basic organization unit of living organisms, capable of many basic life processes. Part III is dedicated to applications of microfluidic devices related to cellular analysis and tissue engineering. The behaviors of particles or cells in microfluidic channels have been found important to understand the motion of particles or cells of interest. Chapter 8 describes the fundamentals of microscale fluid dynamics and key issues relating to biological cell behaviors within microfluidic chips. Different mechanisms available to manipulate cells and recent development in these areas are presented in detail. Chapter 9 describes an application of a glass-based microfluidic device in trapping and automated injection of single mouse embryos for large scale biomolecule testing. Many efforts have also been dedicated to the study of cells and the surrounding culture microenvironments, which is the key to understand the complex cell biology and tissue genesis. Chapter 10 is more relative to current advances of microfluidic platforms for tissue engineering and regenerative medicine applications. Stem cells, special types of biological cells that can divide and differentiate into diverse specialized cell types, are the basic building blocks of the human body, and
the research on stem cells is one of the most fascinating areas. Chapter 11 focuses on the applications of microfluidics technology for molecular and cellular analysis of stem cells.

Part IV focuses on applications of microfluidic devices in diagnostic sensing. Miniaturization helps investigators get rid of the restrictions of low concentration, low volume of samples in protein detection and clinical diagnostics. The focus of Chapter 12 is on the development of immunoassays for antibodies and cytokines analysis on nano-bioarray chips. The impact of fully integrated microfluidic systems on high performance genetic analysis is described in Chapter 13. Recent development in DNA sequencing, gene expression analysis, infectious disease detection and forensic short tandem repeat (STR) typing with integrated microfluidic platforms has been reviewed. Many conventional diagnostic methods require bulky and expensive instruments, limiting their applications in resource-poor settings, especially in developing nations. Paper-based analytical devices have been developed for low cost and easy-to-use diagnostic applications. The ability to fabricate microfluidic channels in paper to perform parallel analysis of various biochemical analysts has been demonstrated. Chapter 14 summarizes recent advances in paper-based microfluidic devices. In addition, rapid and multiplexed detection of viral infection is highly desired in many diagnostic applications. Thus, attention has been given to microfluidic POC devices for sensitive viral detection with high specificity based on immunoassays and nucleic acid-based testing in Chapter 15. Furthermore, microfluidic devices have been applied in the field of pancreatic islet transplantation as a clinical therapy for diabetes and radiochemical synthesis for medical imaging in clinical practices, as discussed in Chapters 16 and 17, respectively. In Chapter 16, microfluidic devices are used for the study of pancreatic islet and β-cell physiology and disease pathophysiology. Chapter 17 focuses on the topic of microfluidic devices for radiochemical synthesis in production of radioactively labeled tracers for Positron Emission Tomography and Single Photon Emission Computed Tomography, which are commonly used to quantify biochemical processes in live organisms.

Xiujun James Li and Yu Zhou
August, 2013