Microfluidic Separation and Detection Technologies

Subjects: Public, Environmental & Occupational Health | Engineering, Mechanical

Contributor: Xiangzhi Zhang

Separation and detection are ubiquitous in our daily life and they are two of the most important steps toward practical biomedical diagnostics and industrial applications. A deep understanding of working principles and examples of separation and detection enables a plethora of applications from blood test and air/water quality monitoring to food safety and biosecurity; none of which are irrelevant to public health. Microfluidics can separate and detect various particles/aerosols as well as cells/viruses in a cost-effective and easy-to-operate manner. There are a number of papers reviewing microfluidic separation and detection, but to the best of our knowledge, the two topics are normally reviewed separately. In fact, these two themes are closely related with each other from the perspectives of public health: understanding separation or sorting technique will lead to the development of new detection methods, thereby providing new paths to guide the separation routes.

microfluidic system | lab-on-a-chip | separation | detection | public health

1. Introduction

Public health is closely related to human wellbeing at diverse levels from our neighbor community to the national or even global security, covering the prevention, control, and treatment of major diseases, especially infectious diseases and noncommunicable chronic diseases, as well as supervision and control of food, drug, and public environmental sanitation. The infectious diseases include avian influenza, influenza, mad cow disease, an acquired immunodeficiency syndrome (AIDS), severe acute respiratory syndrome (SARS), and dengue fever, while noncommunicable chronic diseases include cancer, diabetes, and hypertension. When an infectious disease affects a large geographical area, it may cause death, destroy cities, politics, countries, disintegrate civilization, and even annihilate ethnic groups and species. For example, the influenza pandemic claimed a high death toll in 1918, and SARS transmitted from bat broke out in 2002, affecting public health seriously. Recently, SARS-CoV-2 virus has caused the unprecedented COVID-19 pandemic to occur and spread rapidly all over the world since December 2019. Up to 25 February 2021, there have been 111,999,954 confirmed cases and 2,486,679 confirmed death of COVID-19 around the world, posing a great threat to human health. All these infectious diseases severely impact the development of the local economy and social stability. Infectious diseases can spread through air transmission, water transmission, food transmission, contact transmission, soil transmission, vertical transmission, body fluid transmission, and fecal oral transmission. Each infectious disease is caused by its specific pathogen, including viruses, bacteria, fungi, or parasites. Based on the necessary conditions for infectious diseases such as the infection source, transmission route, and susceptible populations, three strategies can be deployed to manage infectious diseases via controlling the source of infection, cutting off the transmission routes, and isolating the susceptible populations, respectively. From the perspective of patients, the key lies in early detection, early diagnosis, early report, and early isolation. There are two main diagnostic targets for infectious diseases: pathogens or a specific antigen, antibody, or nucleic acid of an infectious pathogen. Some of the techniques are time-consuming, labor-intensive, expensive, and unable to be carried out on-site detection because the use of bulky instruments is inevitable, which thereby hinders their applications and makes them insufficient to achieve rapid, accurate, and on-site diagnosis during a pandemic, especially in the most common and serious resource-poor areas.

In addition to infectious diseases, noncommunicable chronic diseases are also an important threat to human health, such as cardiovascular and cerebrovascular diseases, cancer, chronic respiratory diseases, and diabetes, which are mainly caused by unhealthy lifestyle and living environment. These kinds of diseases have a high incidence rate, disability rate, mortality rate, and medical expense, which can be thawed by early diagnosis and treatment. The common diagnostic methods in clinic for noncommunicable chronic diseases are tissue biopsy and liquid biopsy. However, tissue biopsy is limited by sampling bias, sampling difficulty for deep tissue, and harm to patients, while liquid biopsy presents the challenges of a few samples, complex background, and gene typing polymorphism.

The health safety of food, drug, and public environmental sanitation has become a global question, such as excessive content of metals and additives, pesticide residues, and microbial contamination in food, water, gas, and soil. In the last few years, food safety accidents have occurred repeatedly. Improved food safety analysis and testing are needed to control food contamination. However, the traditional detection technology based on instrumental analysis has the disadvantages of expensive instruments, long cycle, large material consumption, complex operation, and low sensitivity, which cannot satisfy the demand of on-site, real-time, fast, and portable detection of food. Meanwhile, with the increase in environment pollution, related detection, monitoring, and cleanup technologies should be developed to detect and collect toxic wastes and pollution.

2. Microfluidic technology

In the past decade, microfluidic technology has developed rapidly and microfluidics can lead to the combination of the sample pretreatment, separation, and detection processes into a small chip to realize the miniaturized, automated, and multifunction integrated analysis system, which find wide applications in molecular/cell biology, chemical/gene analysis, medicine, food safety, environment sensing, and other fields, because of the advantages such as less sample consumption, fast detection speed, facile operation, multifunctional integration, small size, and portability. Among the numerous applications, microfluidic sensors have been developed to detect toxic gases in industrial wastewater, such as drinking water, heavy metals, and other waterborne pathogens. Microfluidic chip technology can be further integrated with electrochemical techniques, optical techniques, magnetic techniques, mass spectrometry, and other techniques to realize the separation and detection of targeted samples.

There are several reviews that focus on the application of microfluidic technologies in disease detection, food safety analysis, or environmental monitoring and detection. Nevertheless, there are inadequate studies focusing on unveiling the connection of microfluidics with public health, which has been arising as a global issue especially given the present COVID-19 crisis sweeping across the world. For example, it is helpful for determining infection risks to understand aerosol concentrations and persistence in public spaces because they play an important role in coronavirus transmission. However, it is difficult to measure the concentrations, which requires specialized equipment. The challenge may be tackled using microfluidics by taking advantaging of their high throughput capability and high integration level. Thanks to the advances in microfluidic development for cell separation and detection, point-of-care diagnostics are allowed, and monitoring of individual health conditions at home is possible, which greatly eases the public healthcare burden. The present study aims to give an overview of state-of-art microfluidic separation and detection technologies from the perspectives of public health, and we focus on separation and detection because they are two of the most important steps toward practical applications in disease detection, food safety analysis, and environmental monitoring and detection. The reviewed topics are closely associated with public health based on three aspects: (1) Prevention and early monitor of infectious diseases such as detection of COVID-19 viruses necessitates the demand to apply the microfluidics-based separation and detection methods; (2) Microfluidics also inspires novel routes to develop the vaccine products to effectively treat the diseases which may result in big public health impacts; and (3) The rapid growth of microfluidics-based separation and detection technologies also leads to point-of-care diagnosis which enables people to monitor their health conditions using portable devices at home, and this significantly mitigates the needs to seek medical assistance at hospitals and therefore promotes the public health level. The review paper is structured as follows: first, various microfluidic separation methods for public health are summarized and discussed. Subsequently, microfluidic detection methods applied to public health are systematically presented. Finally, the challenges and prospects of microfluidic separation and detection technology are discussed.