JOHESAM Journal of Health Sciences and Management, 2024; 4 (2): 56-64 (ISSN 2757-6914); DOI: 10.29228/JOHESAM.37

Microfluidic Technology for Detection

Mikroakışkan Teknolojisinin Tanıda Kullanımı

Buse AY[1], Ahmet KOLUMAN[2]

[1] Izmir Democracy University, Izmir, Türkiye
[2] Pamukkale University, Faculty of Technology, Biomedical Engineering, Pamukkale/Denizli, Türkiye

Sorumlu Yazar: Buse AY
E-mail: busebelindaay@gmail.com

Gönderme Tarihi: 17.03.2024 **Kabul Tarihi:** 19.05.2024

ABSTRACT

Microfluidics focuses on the movement and interactions of fluidic substances, such as liquids or gases, on a microscopic scale. In general, it provides to take controls and handles fluids by utilizing devices and systems that possess microscale structures within 1-500 micrometer. Microfluidic technology has emerged as a powerful tool for detecting various substances, including pathogens, biomarkers, pesticide residues, gases, and airborne microorganisms. Detection is a key aspect of microfluidic devices by quantifying analyte concentrations on the order of micrometers or determining the mere absence or presence of an analyte.

In microfluidic systems, the detection of various analytes can be achieved through various integrated modules that utilize different physical principles, including electrochemical, optical, magnetic, and thermal methods. The versatility of these integration modules enables researchers to develop their detection strategies to suit diverse application requirements in biomedical, clinical, environmental monitoring, and food safety fields. The benefits of microfluidic systems include rapid detection, ease of use, cost-effectiveness, and high accuracy for the identification of infectious diseases.

In this review, the utilization of detection methods within microfluidic systems and their applications across various domains including biomedical, clinical, environmental monitoring, food safety, and point-of-care diagnostics are being extensively explored by searching English articles published between 2001-2023 in academic databases Pub Med and Google scholar .The review aims to provide a comprehensive understanding of how microfluidic technology enhances detection capabilities, thereby contributing to advancements in healthcare, environmental science and food safety.

Keywords: Microfluidics, Detection, Electrochemical detection, Optical detection, Magnetic detection.

ÖZ

Mikroakışkanlar, sıvılar veya gazlar gibi akışkan maddelerin mikroskobik ölçekteki hareketi ve etkileşimleri üzerine odaklanır. Genel olarak 1-500 mikrometre arasında mikro ölçekli yapıya sahip olan bu cihazlar ve sistemler, sıvıları kontrol etmeyi ve işlemeyi sağlar. Mikroakışkan teknolojisi patojenler, biyobelirteçler, pestisit kalıntıları, gazlar ve havadan yayılan mikroorganizmalar gibi çeşitli maddeleri tespit etmek için güçlü bir araç olarak ortaya çıkmıştır. Mikroakışkan cihazların tespit özelliği, analit konsantrasyonlarını mikrometre düzeyinde ölçerek veya bir analitin basit varlığını veya yokluğunu belirleyerek anahtar bir özelliktir.

Mikroakışkan sistemlerde, çeşitli analitlerin tespiti, elektrokimyasal, optik, manyetik ve termal yöntemler gibi farklı fiziksel prensipleri kullanan çeşitli birleştirilmiş modüller aracılığıyla gerçekleştirilebilir. Bu entegrasyon modüllerinin çok yönlülüğü, araştırmacılara biyomedikal, klinik, çevresel izleme ve gıda güvenliği alanlarında çeşitli uygulama gereksinimlerine uygun tespit stratejileri geliştirmelerini sağlar. Mikroakışkan sistemlerin faydaları, enfeksiyon hastalıklarının tanımlanması için hızlı tespit, kullanım kolaylığı, maliyet etkinliği ve yüksek doğruluk içerir.

Bu derlemede, mikroakışkan sistemlerdeki tespit yöntemlerinin kullanımı ve biyomedikal, klinik, çevresel izleme, gıda güvenliği ve bakım noktası tanıları gibi çeşitli alanlardaki uygulamaları kapsamlı bir şekilde incelenmektedir. Bu inceleme için PubMed ve Google Scholar akademik veri tabanlarında 2001-2023 yılları arasında yayınlanmış İngilizce makaleler taranmıştır.

Derleme, mikroakışkan teknolojisinin tespit yeteneklerini nasıl geliştirdiğine dair kapsamlı bir anlayış sağlamayı ve böylece sağlık hizmetleri, çevre bilimi ve gıda güvenliği alanlarındaki gelişmelere katkıda bulunmayı amaçlamaktadır.

Anahtar Kelimeler: Mikroakışkan, Tespit, Elektrokimyasal Tespit, Optik Tespit, Manyetik Tespit.

DOI: 10.29228/JOHESAM.37

1. INTRODUCTION

Microfluidics in detection

Microfluidic devices have gained significant attention for their potential detection applications owing to their ability to manipulate small volumes of fluids with high precision and sensitivity (Zimmerman et al., 2006; Nasseri et al., 2018). It has the potential to integrate all experimental processes in a research laboratory (sample preparation, reaction, separation, and detection) into a microscale device (Wang et al., 2018). The detecting system is the essential component that is in charge of signal acquisition ever since the micro total analysis system (mTAS) was originally presented by Manz et al. in 1990 in order to read out the analytical data acquired by a microchip (Jin et al., 2018). These devices typically consist of microchannels, chambers, valves, pumps and integrated components such as sensors, detectors and actuators. One of the most promising applications of microfluidics is its use in detection. Microfluidic devices can accurately and precisely identify a wide range of substances, including biomarkers, drugs, toxins, and pathogens. Furthermore, these devices can integrate various detection techniques, such as optical, electrical, and chemical sensing, into a single device, enhancing their capabilities in detection applications. Such as, programmable microfluidic devices based on paper are a well-known type of microfluidic device. It provides improved control over the manipulation of fluid samples, allowing for the automation of single – and multi-step assays as well as the very sensitive detection of a variety of biomarkers (Soum et al., 2019).

Microfluidic electrochemical devices offer numerous advantages in the realm of detection, primarily due to their small sample volume requirement. This feature not only reduces the amount of sample needed for analysis but also enables rapid and high-throughput detection. Additionally, these devices possess on-chip sample preparation capabilities, which streamline the overall detection process by minimizing manual sample handling and reducing the risk of contamination. Furthermore, the benefits of microfluidic electrochemical devices include multiplexed detection, on-chip sample preparation, reduced sample volume needs, and miniaturization, making them particularly suitable for heavy metal detection applications (Li et al., 2019).

The integration of microfluidic systems with on-chip pumping and detection functionalities has led to the development of innovative platforms for long-term perfusion cultures and real-time monitoring of tissue models. These integrated microfluidic devices have the capacity for online and continuous detection applications, allowing for the long-term dynamic investigation of tissue model cellular responses and metabolic processes. For long-term perfusion culture and online tissue model monitoring, integrated microfluidic devices with on-chip pumping and detection capabilities have been created, indicating the possibility for continuous and real-time detection applications (Kimura et al., 2008). Electrode placement may be precisely controlled to enable sensitive and specific detection with the use of 3D printed electrodes in microfluidic systems, providing an affordable and adaptable solution (Erkal et al., 2014). The integration broadens microfluidic detection, analyzing diverse analytes with precision. Using 3D printed microfluidic devices with integrated electrodes is a major step forward in efficient analyte analysis, with implications for biomedical research, diagnostics, and environmental monitoring. Furthermore, the use of microfluidic systems has demonstrated potential for label-free in-flow detection of individual DNA molecules, presenting fresh possibilities for the detection and identification of individual molecules in microfluidic devices (Gong e al., 2014). Despite the many benefits that microfluidic devices provide for detection applications, issues have been noted with low sample volume and the requirement for sensitive analytical procedures (Chabinyc et al., 2001). Overall, they offer a wide range of detection capabilities, from biomarkers to heavy metals, and from single DNA molecules to tissue models. The integration of various methodologies and the development of sensitive analytical techniques have expanded the potential of microfluidic devices for detection applications.

The aim of this review is to look at the improvements and possible uses of microfluidic devices in detecting procedures with investigating how these devices, with their ability to precisely manipulate small fluid volumes, integrate various experimental processes, and incorporate diverse detection techniques, can revolutionize the field of detection in a variety of domains including biomedical research, diagnostics, and environmental monitoring.

Types of detection modules in microfluidic

Electrochemical Detection

Electrochemical microfluidics integrates electrochemical detection into microfluidic systems. This involves incorporating sensors and electrodes in microfluidic channels for precise analyte detection. Key components include microfluidic chambers, channels, electrodes, sensors, control systems, and data gathering systems. Channels and chambers are designed for specific functions, while electrodes facilitate electrochemical detection, typically using a working and reference electrode setup. To complete the electrochemical circuit and significantly boost the system's sensitivity without compromising the microfluidic device's physical design, a coulter counter electrode may also be added (Murali et al., 2009). It's employed in microfluidic systems for impedance cytometry (Brazey et al., 2018). Numerous methods, including amperometric (AD), conductivity-based, voltametric, electrochemical impedance spectrometry, chronocoulometric, or redox cycling, can be used for electrochemical detection in microfluidics devices (Gencoglu et al., 2014).

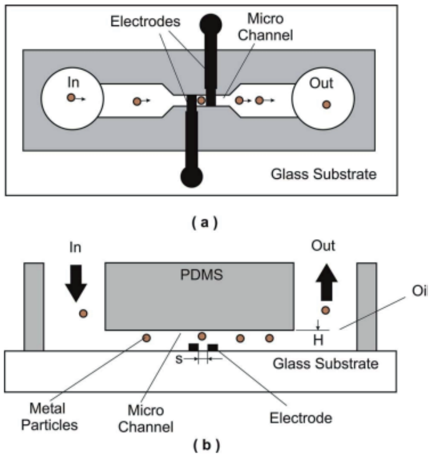

Figure 1. *Schematic of the electrochemical based microfluidic sensor design for metal wear detection with top view (a) and sectioned front view (b) (Murali et al., 2009).*

Amperometric analysis measures current under a constant electric potential between electrodes. The current reflects analyte flux to the electrode surface. Initially high, it declines as analyte depletion extends beyond the surface, reducing the concentration gradient and current. Time-dependent behavior of current can be used to infer the concentration of analyte in the solution. A polymer-based microfluidic device with an amperometric system, for example, is presented by Ruecha et al. for the very sensitive detection of cholesterol (Ruecha et al., 2011).

Voltammetry, a widely used technique, assesses system reversibility. By applying varying electrical potential between electrodes, it measures resulting current over time, unlike amperometry's constant potential. Jiang et al. demonstrated voltammetry's effectiveness in a published paper. They create a microfluidic gene device that uses cyclic voltammetry to detect DNA electrochemically (Jiang et al., 2012). Automated As determination in water using an electrochemical sensor incorporated into a modular microfluidic system is a well-known example of voltametric approaches (Gimenez-Gomez et al., 2019).

Electrochemical impedance spectroscopy has gained popularity in biosensing due to its capability to detect binding events occurring on the surface of a transducer. In electrochemical impedance spectroscopy (EIS), a small sinusoidal AC perturbation is applied along with a DC potential between working electrode (WE) and reference electrode (CE). Using Ohm's law, impedance may be calculated by logging the resultant current's magnitude and phase angle as a function of AC frequency (Rackus et al., 2015). The article by Ali et al. provides a clear illustration to find biomarkers for breast cancer, they developed a microfluidic immuno-biochip (Ali et al., 2016).

Microfluidic types including impendance-based, discrete (like droplet-based) and paper-based (Lindsay et al., 2007) have several benefits, such as downsizing, low sample volume needed, and the possibility of multiplexed detection and on-chip sample preparation. It has been demonstrated that electrochemical detection in microfluidic devices provides real-time detection for a variety of analytes, such as heavy metal ions, biomarkers, and DNA sequences, along with great sensitivity, exceptional selectivity, remarkable stability, and repeatability (Li et al., 2013; Hong et al., 2016; Ming et al., 2021).

Optical Detection

The widespread use of optical instruments in laboratories has made optical detection the most widely used method for quantitative proteome analysis and the diagnosis of infectious diseases. Two main types exist for optical detection in microfluidic devices: "off-chip" with separated detection units, and "on-chip" merging fluidic and optic components. The detection units such as light source, mirrors, and detectors are separated from the Microfluidic platforms. Other approach is the "on-chip" paradigm, where fluidic functional units are produced alongside or merged with the optics. The term "optofluidic" is also used to describe this kind of Microfluidic (Gai et al., 2011).

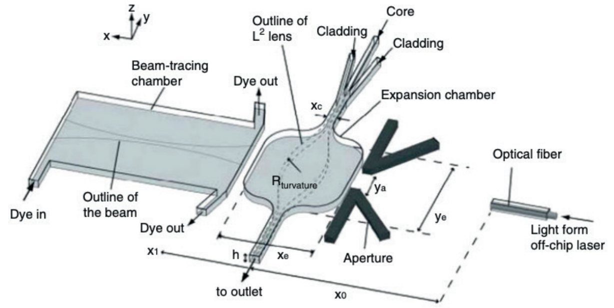

Figure 2. *Experimental setup for focusing light exiting an optical fiber in optofluidic microfluidic devices (Gai et al., 2011).*

Free-space optical detection techniques encompass surface-plasmon resonance, chemiluminescence, absorbance, fluorescence, and Raman spectroscopy/imaging. Microfluidic biosensors similarly utilize these techniques, showcasing their versatility in detection within microfluidic systems (Pires et al., 2014). Case in point, Wang and team workers demonstrates a SERS – microfluidic device using nanotechnology techniques. To regulate the nanogroove characteristics, the device is created by means of tip-based nano scratching utilizing atomic force microscopy (AFM). The synthesized nanostructures are utilized to detect the Raman spectra of rhodamine 6G (R6G). The results indicate possible uses for these kinds of microfluidic devices in chemical or biological molecular detection applications (Wang et al., 2023). A different example is provided by Wang et al. They mentioned a thin-film organic photodiode for microscale chemiluminescence that is based on solutions. These photodiodes are easily incorporated into planar chip-based systems due to their straightforward layered nature. And they were assessed for microscale chemiluminescence detection (Wang et al., 2007). Additionally, the outcome demonstrates outstanding linearity and a detection limit of 10 micrometers for hydrogen peroxide.

Optofluidic chips combine microfluidics with optical components, achieving higher miniaturization as more functions are integrated onto the chip. Unlike free-space optic systems, integrated optical microfluidic systems don’t require alignment and are technician-independent. Khosla et al.’s work demonstrates a microfluidic whispering gallery mode (WGM) biosensing device that effectively delivers and detects target molecules (Khosla et al., 2014). Since their mode volume is so small, WGM resonators are optical sensors that are highly sensitive. The researchers also discovered that when microfluidics and WGM sensing are combined, a highly customizable system with a yield for a certain concentration and the capacity to improve sensing time by modifying the microfluidic system’s input power and flow characteristics is produced. Particles and molecules as small as a single BSA protein (about 6 nm in radius) may be detected and analyzed for femtomolar concentrations by combining microfluidics and WGM.

Generally, there are several key components to optical detection within optofluidic, planar optical waveguides, micro lenses, optical lasers, and optical detectors. An optical waveguide is a physical structure designed to transmit light along axis, typically consisting of a “core/cladding” composition. To illustrate, Parker et al. demonstrates the generation of uniform droplets within a uniaxial optofluidic lab-in-fiber setup (Parker et al., 2022). They provide reliable and compact alignment by combining droplet microfluidics with laser-induced fluorescence (LIF) detection through the use of an optical side-coupling fiber known as a periscope fiber. In addition, they demonstrate the usefulness of the apparatus by identifying reverse-transcription loop-mediated isothermal amplification (RT-LAMP) products for COVID-19 diagnostic purposes.

Magnet Beads Detection

Magnetic beads microfluidic detection involves the use of magnetic beads, which are small, functionalized beads that can bind to the specific target molecules such as protein, nucleic acids, or cells within microfluidic systems. These magnetic beads are often coated with ligands that can selectively bind to the target molecules of interest. Typically, magnetic bead microfluidic detection system involves a sample containing the target molecules that as the sample flows in Microfluidic channels, an external magnetic and integrated various detection systems such as fluorescence or electrochemical methods can be used to detect the presence or concentration of the bound molecules on the surface of the bead. A new cell detection device has been presented by Liu et al. that combines microfluidic Coulter counting technology with the magnetic bead cell assay (Liu et al., 2016). The device accurately recognizes certain target cells and measures concentration and cell size distribution. Using resistive pulses from the counters, the transit time and cell size are precisely determined. According to the research, the transit time delay rises linearly as the target cell ratio increases, with an estimated 5.6% detection limit. The gadget may help with stem cell extraction and characterization by detecting target cells quickly and reliably, as shown by its straightforward setup and simple sample preparation.

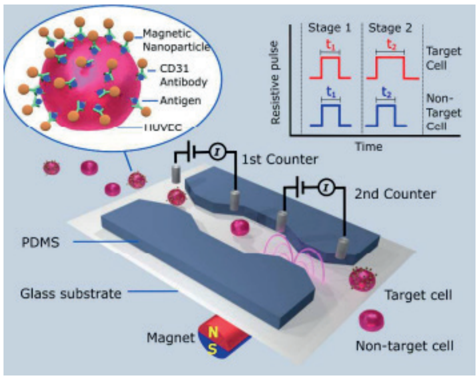

Figure 3. *Schematic of the magnetic bead based microfluidic cell assay which is based on two micro-Coulter counters (Liu et al, 2016).*

Thermal Detection

Among the various methods for counting and detecting particles that have been examined, heat has not yet been thoroughly explored. Through microfabrication, it is now possible to produce low-cost but highly sensitive thermometers capable of detecting tiny fluctuations in the thermal characteristics of a liquid within a microchannel. As particles suspended in a fluid influence the thermal properties of the fluid, a sensitive thermometer essentially serves as a particle counter by detecting these changes. A microscale thermometer could analyze the thermal properties of cells and other particles or droplets, aiding in their identification and characterization. One of the brilliant examples of this type of detection in microfluidic is developed by Liu et al. (Liu et al., 2014). Using hexavalent chromium [Cr (VI)] as a model analyte, a microfluidic flow injection analysis (μFIA)–TLM device was created for the quick detection of contaminants by colorimetric reactions. Additionally, contamination-free, instrument-free, visual detection of SARS-CoV-2 has been made possible by the combination of isothermal amplification, CRISPR cleavage, and lateral flow detection in a single, closed microfluidic device. A unique method for the quick and accurate detection of SARS-CoV-2, the virus that causes COVID-19, is presented by Li et al. (Li et al., 2022). This novel technique makes use of a self-contained microfluidic system, which is straightforward, sensitive, and doesn’t require specialist tools. The microfluidic device combines lateral flow sensing, CRISPR cleavage, and isothermal amplification to provide visible, contamination-free viral detection. Without the requirement for power, the microfluidic chip may be incubated using a cheap, portable hand warmer. The technique has been clinically verified using nasopharyngeal swab samples and has demonstrated good sensitivity, specificity, and accuracy in detecting SARS-CoV-2 RNA down to 100 copies.

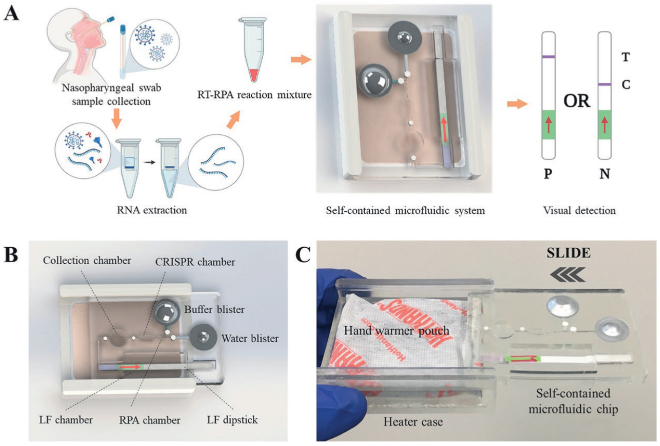

Figure 4. *Self-contained microfluidic design for detection of SARS-CoV-2 by Li et al. ((Li et al., 2022).*

Applications of microfluidic based detection

Biomedical Applications

Microfluidic detection has gained significant attention in biomedical applications, particularly in isolating and detecting biomarkers such as exosomes and circulating tumor cells. In the realm of biomedical field, microfluidic devices have been applied to the detection of biomarkers and cancer cells at incredibly low concentrations, including micro-RNA, indicating their promise for sensitive and accurate detection in biomedical settings and treatment monitoring (Chen et al., 2012).

The integration of magnetic nanoparticles in microfluidic systems has enabled the development of highly sensitive and specific detection methods. To define the inductance of electrical resonant circuits in magnetometers, for example, the magnetic characteristics of particles in microfluidic chambers have been used, leading to a shift in the resonance frequency (Abedini-Nassab et al., 2021).

Further benefits for identifying active chemical and biological species come from Chandrasekaran et al.'s investigation of an integrated microfluidic biphotonic device intended for laser-induced fluorescence detection (Chandrasekaran et al., 2010). The chip combines an opto-microfluidic chip made on a silicon-polymer hybrid platform with a Spectrometer-on-Chip device, designed for multiple fluorescence detections at different emission wavelengths. The device's potential for high-throughput detection of chemical and biological materials is demonstrated through experimental validation utilizing antibody particles labeled with Alexafluor 647. Another brilliant example is microfluidic paper-based wearable electrochemical biosensor for reliable cortisol detection by Fiore et al. (Fiore et al., 2023). A new paper-based microfluidic system for reagent-free cortisol analysis in perspiration is presented. The device combines capillary-driven microfluidics and filter paper to regulate reagent flow. It detects cortisol using magnetic beads with monoclonal antibodies, facilitated by acetylcholinesterase enzyme-mediated competitive interaction. It can detect cortisol concentrations from 10-140 ng/mL and is integrated with a wireless Near-Field Communication module for wearable cortisol analysis. Its accuracy was validated during real-time sweat cortisol analysis on a volunteer during physical activity.

Microfluidic techniques have also been employed for the detection of cancer cells, demonstrating the versatility of microfluidic platforms in various biomedical applications (Nguyen et al., 2017). To illustrate, a study introduces an electrochemical Lab-on-a-Disc (eLoaD) platform designed for automated quantification of ovarian cancer cells (SKOV3) from whole blood by Nwankire et al. (2015). The platform combines label-free electrochemical impedance for sensitive detection and targeted capture with advanced sample processing techniques like blood separation and cancer cell extraction. It has a wide dynamic linear range and can perform five parallel tests, making it a promising tool for biomedical applications such as cancer cell identification.

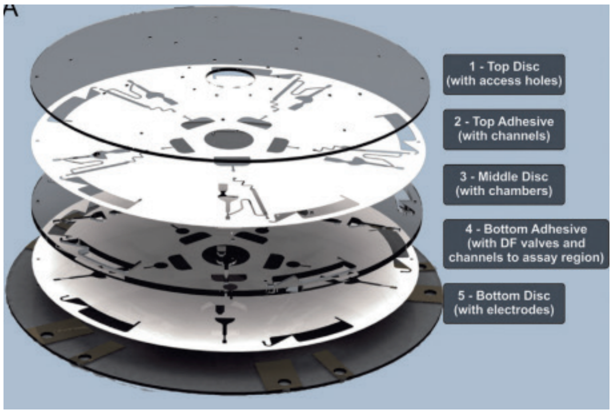

Figure 5. *The 5-layer microfluidic disc platform which is developed by Nwankire et al. (2015)*

Clinical Applications

Within clinical applications, microfluidic devices play a crucial role in various diagnostic procedures, including the detection of the pathogens, monitoring of disease progression, and screening for biomarkers indicative of specific health conditions. By integrating various sensing mechanisms, such as optical, electrical or chemical sensors into Microfluidic devices, research can detect specific biomolecules or cells with high accuracy and speed. A new microfluidic device detects Cry1Ab protein with high sensitivity and selectivity. It contains a microfluidic flow cell and a printed gold electrode chip. Anti-Cry1Ab aptamer-coated magnetic beads bind to Cry1Ab protein, forming modified beads. These are then introduced into the flow cell for measurement, showing a detection limit of 0.015 nm and good linearity from 0 to 0.2 nm concentration at 358.3 Hz. In support of food safety studies, this method provides a sensitive, quick, and targeted substitute for identifying the transgenic protein Cry1Ab (Jin et al., 2017).

Another example is a reproducible microfluidic device utilizing surface-enhanced Raman spectroscopy (SERS), composed of a disposable SERS substrate and a reusable microfluidic channel by Lee and team (Lee et al., 2021). The SERS substrate is created using electrodeposition and nanoimprint lithography, while the microfluidic channel is made through mechanical processing. Assembly is facilitated and secured with screws. The SERS substrate guarantees reliable and sensitive detection due to its excellent enhancement factors, signal consistency, and repeatability. Target molecules can be accurately detected using the disposable substrate. The successful identification of miR-34a at a low concentration of 5 fM showcases its practical utility.

Consequently, the use of microfluidics in clinical settings offers several advantages, including minimally invasive sampling, reduced sample consumption, and rapid results which can lead to timely and effective patient care. Case in point, Yao et al. introduce a telemedicine system employing an integrated microfluidic chip for rapid insulin detection (Yao et al., 2013). The system uses the internet to remotely transmit test results to off-site medical specialists for diagnosis. It employs a microfluidic chip with pneumatic micropumps, a micromixer, and microvalves to automate insulin detection via a double-antibody sandwich chemiluminescence immunoassay. This microfluidics-based telemedicine system shows promise for future diabetes point-of-care screening.

Moreover, the incorporation and implementation of optical detection and microfluidics in immunosensors have been a subject of research, highlighting the potential of microfluidic technology in medical diagnostics (He et al., 2016). And advances in microfluidic platforms have enabled multiplex detection of infectious diseases, including microfluidic immunosensors and microfluidic nucleic acid sensors (Chen et al., 2023).

Environmental Monitoring

The integration of microfluidic technologies in environmental monitoring has garnered significant attention due to their potential to revolutionize detection and analysis processes. Microfluidic systems offer precise manipulation of fluid streams in microscale dimensions, making them valuable tools for on-site environmental monitoring and detection (Yew et al., 2019). Furthermore, the ability of microfluidic platforms to preconcentrate samples from dilute solutions has implications for environmental monitoring, as it enables the detection of contaminants in various environmental matrices (Fu et al., 2018). The versatility of microfluidic platforms has led to their widespread application in the field, signifying their importance in addressing environmental challenges. Additionally, microfluidic detection strategies, including optical and electrochemical techniques, have been explored for the analysis of environmental pollutants, highlighting the potential of microfluidic systems in environmental monitoring for instance. An autonomous microfluidic detection device was designed by Milani et al. to determine iron (Fe II) and manganese levels in water using colorimetric detection (Milani et al., 2015). The device featured a cylindrical housing with a PMMA microfluidic chip, LEDs, lithium batteries, a microprocessor, and custom syringe pumps. Iron levels were measured with ferrozine and manganese levels with the PAN technique. The on-chip optofluidic cell's dimensions allowed sensitive detection with reduced reagent and sample use. Mn Limit of detection (LOD) was 28 nM, and for Fe was 27 nM, with linear ranges of 27-200 nM and 0.28-6 µM, respectively. Iron analysis took five minutes, and manganese took 10 minutes. The method successfully analyzed seawater samples, unaffected by high salt concentrations. The industrialization of microfluidic chip technology is anticipated to drive advancements in environmental sensing, emphasizing the role of microfluidics in future environmental monitoring endeavors (Gao et al., 2020).

As the field of microfluidics continues to advance, it presents new opportunities for enhancing environmental analysis, with the potential for low-cost, high-sensitivity, and rapid detection of environmental contaminants. The combination of microfluidic systems with advanced detection methods, such as real-time fluorescence detection, further enhances their utility in environmental monitoring, offering improved capabilities for detecting contaminants and biological specimens. Moreover, the development of low-cost microfluidic platforms has the potential to democratize environmental monitoring, making it more accessible and affordable. I.e. using a vortex t-structure microfluidic sensor chip, Li et al. have devised a novel approach to real-time water quality monitoring that overcomes the shortcomings of current COD (chemical oxygen demand) measurement techniques (Li et al., 2022). Real-time monitoring of river contaminations is challenging due to complex and lengthy procedures. The new system, based on microfluidic technology and ozone chemiluminescence, offers benefits like ease of use, rapid testing, and minimal environmental impact. Tests confirm the chip's ability to generate measurable ozone bubbles, aiding online river water quality monitoring. Microfluidics, coupled with gold nanoparticles' optical properties, show promise in enhancing environmental monitoring methods. The promise of microfluidics in environmental monitoring and public health has been demonstrated by studies on the application of microfluidic-based systems for the detection of gases and airborne diseases (Kaaliveetil et al., 2022). Overall, the integration of microfluidic technologies in environmental monitoring holds great promise for revolutionizing the detection and analysis of environmental pollutants, offering new avenues for addressing environmental challenges.

Food Safety

Food contamination, a global concern, particularly affects developing nations and poses significant health risks due to harmful substances in food. These contaminants include chemicals and microorganisms, categorizing contamination into chemical and biological types. Rapid and accurate detection methods are crucial to mitigate the threats posed by food contamination to human well-being. Microfluidic approaches for controlling and detecting chemical contaminants like heavy metals, pesticides and antibiotic residues in food samples. For instance, Li et al. (2021) developed a rapid detection of methyl parathion pesticide by using Microfluidic paper-based chip. A technique developed to detect pesticides like parathion-methyl (PM) utilizes high sensitivity and selectivity. The method employs silver terephthalate metal-organic frameworks and carbon quantum dots with Fe_3O_4 nanozyme for amplification in a dual catalytic technique. An electrochemical microfluidic paper-based chip integrates a molecularly imprinted polymer (MIP) and Fe_3O_4/C-dots@Ag-MOFs on its surface. PM absorption by the MIP in the reaction zone reduces the current response, leading to a low detection limit of 1.16×10^{-11} mol L^{-1} and good recovery rates in environmental and agricultural samples. This approach improves sensitivity and selectivity and holds potential for detecting various target analytes using microfluidic paper-based chips.

Microfluidic paper-based analytical devices (µPADs) are cost-effective tools for in-field diagnosis, highlighting microfluidics' role in food safety. Microfluidic technologies are crucial for digital immunoassays with multiplexed capacity and ultrahigh sensitivity in food safety and environmental monitoring. Rapid quantification of contaminants in food products, like milk, is essential for addressing food safety incidents, showcasing microfluidics' pivotal role in ensuring food quality. Standalone devices for food safety testing, along with advancements in microencapsulation and microfluidic-based bio species sensing, underscore microfluidic detection technologies' transformative potential in food safety. Microfluidics' progress offers opportunities for enhanced food safety analysis, providing low-cost, high-sensitivity, and rapid detection of food hazards to mitigate safety risks in the food industry.

Point-of-care Diagnostic

Microfluidic detection technologies have significantly advanced the landscape of point-of-care diagnostics, offering rapid, accurate, and cost-effective solutions for disease diagnosis and pathogen detection. Microfluidic devices have demonstrated their potential in enabling rapid and fully automated detection of infectious diseases, originated from Ebola virus and African swine fever virus, with median times to threshold as low as 10 minutes, highlighting their applicability in addressing urgent public health challenges (Qin et al., 2019; GaoYe et al., 2019). Further, the creation of microfluidic platforms for recombinase-aided amplification (RAA) and loop-mediated isothermal amplification (LAMP) has made it easier to identify and quantify multiple pathogens simultaneously, opening up a promising path for the quantitative point-of-care detection of a variety of infectious diseases (Fang et al., 2010). The versatility of microfluidic platforms has been exemplified in the development of a portable smartphone-based platform for real-time particle detection, offering potential for real-time point-of-care detection in resource-limited settings (Salafi et al., 2019). Microfluidic tech aids chronic illness diagnosis like diabetes via automated chemiluminescence immunoassays for insulin levels. These devices can detect fluid viscosity without labels, showcasing their point-of-care potential. This presents prospects for the quick and affordable characterization of biological samples in point-of-care situations (Jun Kang et al., 2013). The ability of multiplex microfluidic LAMP chips to properly forecast viruses has shown how microfluidic technology may improve point-of-care diagnostics' specificity and accuracy. As a result, the addition of microfluidic detection technologies has greatly improved point-of-care diagnostics' capabilities and provided cutting-edge approaches to illness diagnosis and healthcare monitoring.

In the examination of spectrum of scholarly investigations spanning biomedical, clinical, environmental, food safety, and point-of-care diagnostic applications, this compilation emerges as a distinctive and comprehensive exposition of multifaceted realm of microfluidic-based detection. By synthesizing a wide range of findings and developments across multiple domains, this article contributes to the existing literature by providing valuable insights into the potential and challenges of microfluidic technology. Its holistic approach, organization, and presentation serve to highlight not only the current state of field but also the future prospects and opportunities for advancement. Meticulous attention has been devoted to ensuring the relevance and currency of the sources. Through a rigorous selection process, emphasis has been placed on incorporating scholarly works that represent the latest advancements and insights in the microfluidic-based detection. Therefore, the originality of this compilation lies in its comprehensive coverage, synthesis of existing research, and insights into the diverse applications and potential of microfluidic-based detection across disparate fields.

2. METHODS

The review was conducted using Pub Med and Google Scholar pages by using document analysis method. The search was limited to English articles published between 2001 and 2023 in the academic databases of Pub Med and Google Scholar. The search was provided by searching for 10 keywords by 5 in Turkish and 5 in English. These are mainly; Microfluidics, Detection, Electrochemical detection, Optical detection, Magnetic detection, Mikroakışkan, Tespit, Elektrokimyasal Tespit, Optik Tespit, Manyetik Tespit. As a result of readings and re-elimination, the number of articles were determined as the most suitable and qualified ones.

3. CONCLUSION

In summary, microfluidic technology has shown great promise in various detection applications, ranging from medical diagnostics to environmental monitoring. The integration of advanced detection technologies into microfluidic systems has enabled rapid, sensitive, and specific detection of a wide range of substances, making microfluidics a valuable tool in diverse fields. They offer a wide range of advantages for detection in various applications, including biomedical, clinical, environmental monitoring, food safety, and point-of-care diagnostics. These advantages include precise manipulation of fluids, low sample and reagent consumption, high sensitivity, rapid detection, and portability. In biomedical and clinical applications, microfluidic devices have shown potential in liquid biopsy, disease biomarker detection, and point-of-care diagnostics, offering the benefits of rapid analysis and reduced sample volumes. In environmental monitoring and food safety, microfluidic devices have demonstrated advantages in the rapid and sensitive detection of contaminants and pathogens, contributing to improved safety and quality control. However, challenges exist in the miniaturization of traditional laboratory processes, the integration of complex detection methods, and the development of specific point-of-care microfluidic diagnosis devices. Addressing these challenges will be crucial in fully realizing the potential of microfluidic devices for detection in biomedical, clinical, environmental, and food safety applications. The integration of advanced detection methods, such as surface plasmon resonance, fluorescence, and impedance spectroscopy, and the development of specific point-of-care microfluidic diagnosis devices will be essential for overcoming these challenges and further advancing the field of microfluidic detection.

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How to cite this article: Ay B, Koluman A. Microfluidic Technology for Detection. Journal of Health Sciences and Management, 2024; 4 (2): 56-64. DOI: 10.29228/JOHESAM.37