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Design and Fabrication of Microfluidic Biochips for Early Detection of Sexually Transmitted Diseases

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ABSTRACT
Sexually transmitted diseases (STDs) remain a global health problem that requires early detection and rapid treatment. This study aims to design and fabricate microfluidic biochips for the early detection of several PMS-causing pathogens, such as Chlamydia trachomatis, Neisseria gonorrhoeae, and Trichomonas vaginalis. This research method involves designing chips with microfluidic technology, fabrication using lithography techniques, and testing the sensitivity and specificity of blood, urine, and cervical fluid samples. The results show that the biochip developed has a sensitivity of up to 92% and a specificity of 95%, with a detection time of less than 10 minutes. The biochip is also capable of detecting a variety of pathogens in a single device, making it an efficient diagnostic tool. In conclusion, this microfluidic biochip has the potential to be a fast, cheap, and effective PMS detection tool for use in the field. Further research needs to be conducted to test the sustainability of chip performance under real-world conditions and for further development in the detection of various other pathogens.

Keywords: *Biochip, Microfluidic, Sexually*

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INTRODUCTION

Sexually transmitted diseases (STDs) remain a significant global health problem (Liu et al., 2020). Despite great efforts in prevention and treatment, the incidence rate of STDs continues to increase, especially among young age groups (Cao et al., 2020). Early detection and rapid diagnosis are essential in controlling the spread of PMS, but conventional diagnostic methods often require long periods of time and complex procedures. Therefore, there is an urgent need to develop faster, cheaper, and more accessible diagnostic technologies for PMS detection.

Microfluidic biochip technology has emerged as a potential solution in the field of medical diagnostics (Kim et al., 2022). This biochip integrates various components at a

microscale to perform biological analysis with very small sample volumes (Volk et al., 2021). The main advantage of microfluidic technology is its ability to perform analysis quickly and accurately in one small, portable device. Using the principle of microfluid flow, this technology enables the detection of specific biomarkers in blood or urine samples with high sensitivity.

The application of microfluidic biochips in disease detection has shown promising results in various fields, such as the detection of cancer, diabetes, and bacterial infections (K. Yang et al., 2020). A similar concept has been used to develop a sexually transmitted disease detection tool, although the challenge is to ensure that the biochip can handle a wide variety of different types of pathogens with high accuracy (Z. Li et al., 2021). Previous research has shown that microfluidic biochips can be optimized for simultaneous detection of pathogens through the use of different types of biosensors.

One approach to improve detection performance in microfluidic biochips is to use nanomaterials that can enhance the interaction between pathogens and sensors (Z. Zhao et al., 2021). The use of nanoparticles and graphene-based materials, for example, can increase the sensitivity of sensors and allow the detection of pathogens at very low concentrations (An et al., 2020). This is important considering the large number of STD cases diagnosed at an early stage with a relatively low number of pathogens.

Microfluidic biochips technology also has advantages in terms of lower production costs compared to traditional diagnostic methods (Bruch et al., 2021). With advances in microfabrication techniques, the production cost of these detection devices is becoming more affordable, making them a more cost-effective alternative for use in healthcare facilities with limited resources (Funari et al., 2020). This practicality and cost efficiency allow this technology to be widely applied in various developing countries.

However, there are still several technical challenges that must be overcome to optimize microfluidic biochips for PMS detection (J. Zhang et al., 2020). These challenges include developing a system that can handle sample variations with high consistency, precise microflow regulation, and efficient integration between sensor elements and detection platforms (Tayebi et al., 2020). Further research is needed to improve the design and functionality of these devices so that they can be widely used in the diagnosis of sexually transmitted diseases.

Although microfluidic technology has been applied in a wide range of medical applications, there are still some major challenges in its application for the early detection of PMS (Tang et al., 2021). One of the main issues is the precision and sensitivity of the biochips used to detect PMS-causing pathogens in very small biological samples (Vinoth et al., 2021). Some studies show that sensitivity at the molecular level is often affected by the quality of the sample or the microenvironment in the biochip.

The lack of consistent standards in the design and fabrication of microfluidic biochips for PMS detection is another major obstacle (Xie et al., 2020). Some existing designs are not able to accommodate variations in the samples being tested, be it blood, urine, or other bodily fluids (L. Yang et al., 2021). Without a design that can handle such a

diverse sample, the detection results can become less accurate or unreliable, affecting the effectiveness of diagnosis.

The process of fabricating cheap and accessible microfluidic biochips is also still a challenge (Alizadeh et al., 2020). Many existing technologies require expensive equipment and materials, which limits the ability to produce these devices in large quantities or for users in areas with limited resources (Cui et al., 2020). Some existing methods still require long production times, thus hindering the development of biochips that can be widely accessed in the field.

Early detection of various types of PMS using microfluidic-based methods is also not fully optimal in terms of complex sample processing (Cheng et al., 2020). To detect a wide range of pathogens, microfluidic biochips must be able to separate, identify, and analyze biological components in a sample without cross-contamination (Wang et al., 2021). Accuracy in these analyses is crucial, but some biochips still have limitations in terms of the accuracy of processing complex samples.

Difficulties in improving microfluidic platforms for early detection of PMS are often caused by limitations in fluid flow programming and control technologies (Hur et al., 2020). An integrated microflow system must be able to regulate very small volumes of fluid, but it is often difficult to achieve precise and stable control under varying environmental conditions, such as body temperature and pH.

To fill these shortcomings, this study aims to design and manufacture microfluidic biochips that are more sensitive, accurate, and affordable for early detection of PMS (Xue et al., 2021). Better designs can address the sensitivity and accuracy issues of detection by utilizing more advanced micro-based separation and detection technologies (Senel et al., 2020). By using efficient fabrication techniques and cheaper materials, the biochips produced are expected to be more accessible, especially in resource-constrained areas.

It is important to develop devices that are not only accurate in detecting pathogens, but also capable of handling biological samples of varying quality without sacrificing the reliability of results (Wu et al., 2022). This will ensure that the resulting biochips can be used in a variety of clinical situations, increasing the likelihood of early diagnosis and faster treatment (Lin et al., 2020). Therefore, this research focuses on creating a more standardized and more flexible microfluidic system for detecting various PMS pathogens.

The hypothesis in this study is that the development of better microfluidic biochip design and fabrication, with more efficient sample separation and higher detection sensitivity, will allow for faster and cheaper diagnosis of PMS (Koklu et al., 2021). By filling the gaps in design and production techniques, these biochips are expected to be widely used to detect STDs at an early stage, improving the prognosis and management of the disease worldwide.

RESEARCH METHODS

This study uses a laboratory experiment design with a hardware engineering approach to design and manufacture microfluidic biochips used for early detection of sexually transmitted diseases (STDs) (J. Li & Lillehoj, 2021). This research involves the

steps of design design, chip fabrication, and system testing on biological samples. Experiments were conducted to evaluate the performance of biochips, including sensitivity, specificity, and speed of detection of pathogens that cause PMS.

The population in this study consisted of biological samples that included blood, urine, and cervical fluid taken from individuals infected with STDs (L. Zhang et al., 2020). These biological samples were used to test the biochip's ability to detect various pathogens, such as *Chlamydia trachomatis*, *Neisseria gonorrhoeae*, and *Trichomonas vaginalis*. The sample also includes healthy specimens to verify negative results and ensure the accuracy of the biochip.

The instruments used in this study include devices for microfluidic chip fabrication, such as photolithography machines for micro-pattern manufacturing and polydimethylsiloxane (PDMS) casting tools for micro-channel manufacturing (H. Zhang et al., 2020). In addition, measuring devices such as microscopes for visual observation, image processing systems for data analysis, and biosensor instruments are used to detect interactions between pathogens and chip materials.

The research procedure begins with the chip design stage using CAD software to design the microchannel patterns required for the sample flow (Lao et al., 2020). Once the design is complete, the chip is made through a process of photolithography and PDMS casting. After fabrication, the chips are tested with pre-prepared biological samples and labeled with fluorescent markers. The detection process is carried out by passing the sample through a microchannel and observing the reaction that occurs between the pathogen and the biosensor in the chip. Furthermore, the detection results were analyzed to assess the sensitivity and specificity of the tool in detecting PMS.

RESULTS AND DISCUSSION

The results show that the designed microfluidic biochip has a fairly high sensitivity in detecting pathogens that cause PMS in biological samples. The following table shows the performance of biochips on various pathogens: *Chlamydia trachomatis*, *Neisseria gonorrhoeae*, and *Trichomonas vaginalis*. The detection sensitivity of each pathogen is 92%, 89%, and 85%, with a specificity level of 95% for each pathogen. This data shows that the biochip is able to detect pathogens with an excellent degree of accuracy.

Pathogens	Sensitivity (%)	Specificity (%)	Detection Time (minutes)
Chlamydia trachomatis	92	95	5
Neisseria gonorrhoeae	89	95	7
Trichomonas vaginalis	85	95	6

The table shows that microfluidic biochips have consistent performance in detecting all three pathogens that cause PMS. Although there are slight differences in the sensitivity of individual pathogens, all detection results remain within acceptable ranges for medical applications. The relatively short detection time, which is between 5 to 7 minutes, shows that this biochip is capable of providing fast and efficient results, which is very important in the context of early detection.

In subsequent trials, the data showed that the detection time was getting shorter as the quality of chip fabrication improved. The use of more advanced microfluidic technology in chip design allows for a more controlled sample flow, which affects detection efficiency. In testing with cervical fluid samples, the biochip also showed consistent results with slightly higher sensitivity (93%) compared to blood and urine, which had a sensitivity of 90% and 88%, respectively.

The results of a higher sensitivity test in cervical fluid can be explained by the higher concentration of pathogens in the sample. Cervical fluid has a higher density of cells and microorganisms, which facilitates faster interaction with the surface of the biochip. In addition, the chip design that optimizes the detection area in cervical fluid samples allows pathogens to be more easily detected compared to blood or urine, which may contain fewer pathogens.

The data obtained show that microfluidic biochips can be used for PMS detection with a high degree of accuracy, even in biological samples with lower concentrations of pathogens. The relationship between sensitivity and sample type demonstrates the importance of proper sample selection in diagnostic applications. These results reinforce the claim that microfluidic technology can improve the speed and efficiency of detection of sexually transmitted diseases.

In a case study of blood samples taken from individuals infected with Neisseria gonorrhoeae, the biochip was able to detect the pathogen with a sensitivity of 89% in less than 7 minutes. The results of this detection were then compared with the results of the PCR test, which showed a 95% fit between the two methods. This indicates that microfluidic biochips can serve as a quick and efficient alternative to more expensive and time-consuming diagnostic methods.

The similarity of detection results between biochips and PCR shows that microfluidic biochips have capabilities that are almost equivalent to standard laboratory methods in terms of accuracy. The significant difference in detection time (PCR takes several hours) corroborates the claim that biochips can provide advantages in terms of diagnostic speed and mobility, especially in time-constrained clinical settings.

The relationship between detection speed and conformity with PCR confirms that microfluidic technology can be a very useful diagnostic tool for clinical applications. The advantage in terms of fast detection times makes it ideal for field use or settings with limited resources, where rapid diagnosis is essential for the effective management of PMS.

This research has successfully designed and fabricated an effective microfluidic biochip for the early detection of sexually transmitted diseases (STDs). This biochip shows high sensitivity in detecting major pathogens such as *Chlamydia trachomatis*, *Neisseria gonorrhoeae*, and *Trichomonas vaginalis*, with the highest sensitivity reaching 92%. In addition, this biochip shows excellent specificity, with a value of up to 95%. The fast detection time, which is less than 10 minutes, also makes it an efficient diagnostic tool.

The results of this study are in line with several previous studies that apply microfluidic technology in medical diagnosis. However, the main difference lies in the

ability of these biochips to work with different types of biological samples in one compact and fast device. Some other studies still face obstacles in terms of longer detection times and lower sensitivity in heterogeneous biological samples. The advantage of this study is a simpler but still effective biochip design in detecting pathogens in a more varied sample.

The results of this study show that the use of microfluidic biochips for early detection of PMS has great potential in improving faster and more efficient diagnosis efforts (Yao et al., 2020). The successful detection of various pathogens and biological samples shows that this technology can accelerate decision-making in treatment. This is a sign that microfluidic technology has the potential to be an important tool in public health counseling, especially in combating the spread of PMS.

The main implication of the results of this study is that microfluidic biochips can be used as an inexpensive, fast, and easily accessible diagnostic tool for early detection of PMS (Arduino et al., 2021). With accurate results and short detection times, this technology can help speed up treatment and reduce the spread of sexually transmitted diseases. It also opens up opportunities for wider applications of the technology in the field of medical diagnostics, with a focus on improving accessibility and efficiency.

The results of this study were achieved thanks to the design of the biochip that has been modified to optimize the flow of microfluids and the interaction between biological samples and the detection material inside the chip (Y. Zhao et al., 2020). Microfluidic technology allows for more efficient manipulation of samples at the microscale, reducing the cost and time required for detection. The use of the right materials and fabrication methods also contributes to accurate and fast results.

The next step in this study is to conduct field trials using a wider and diverse sample, as well as test biochips in real conditions in clinics or medical laboratories (Zhuang et al., 2022). In addition, it is important to conduct further testing of the long-term durability and stability of microfluidic biochips under various environmental conditions. Further development also needs to be done to introduce these biochips in a more affordable and accessible setting for the general public.

CONCLUSION

This study found that the microfluidic biochip designed is able to detect pathogens that cause PMS with high sensitivity and specificity (Xu et al., 2021). The most notable result is the biochip's ability to detect multiple pathogens in a single device with a fast detection time of less than 10 minutes. This makes it an efficient and effective diagnostic tool to use in the field, especially in efforts to prevent and treat STDs more quickly.

This research makes an important contribution in developing a new concept in the design of microfluidic biochips for the detection of sexually transmitted diseases (Ardalan et al., 2020). The main contribution of this research is the biochip fabrication method that is able to handle biological samples with high diversity, and is able to provide fast and accurate results. The concept applied in the design of this chip opens up new opportunities in the use of microfluidic technology for a wider range of medical diagnostic applications.

The main limitations of this study are the limited use of samples and the absence of biochip trials on a field scale (Chen et al., 2022). Further research can be focused on testing biochips in real environments with more samples from different populations (Ouyang et al., 2020). In addition, the development of chips for the detection of more pathogens or new variants of PMS is a very important research direction so that this technology can be applied in a global context.

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