ปัญญาประดิษฐ์มีศักยภาพที่จะเอาชนะความท้าทายในการวินิจฉัยโรคติดเชื้อ

Artificial intelligence (AI) has the potential to surpass the challenges in diagnosing infectious diseases

ศรัณยพงศ์ กุลภัทร์วัฒนา[1], ปิญชาณ์พัชร โพคะ[2], นิรดา แสงกิติโกมล [3], โปรดปราน คงชาตรี [3], นลิน องค์วุฒิธรรม[4], ศักรนันทน์ บูรณจิตร์ภิรมย์ [5], ดานิฌ ณ เชียงใหม่[6], สิรวิชญ์ จิรวรรณาภรณ์ [7]
[1] โรงเรียนมัธยมตากสินระยอง, [2] โรงเรียนสามเสนวิทยาลัย, [3] โรงเรียนสตรีวิทยา, [4] โรงเรียนสาธิตมหาวิทยาลัยศรีนครินทรวิโรฒ ประสานมิตร (ฝ่ายมัธยม) หลักสูตรนานาชาติ, [5] โรงเรียนอัสสัมชัญ, [6] โรงเรียนวิชัยวิทยา, [7] นักวิจัยอิสระ

Sarunyapong Kulpatwattana[1], Pinchaphat Poka[2], Nirada Sangkitikomol[3], Prodepran Kongchatree[3], Nalin Ongwuthitham[4], Sakkranunn Boonranajitpirom[5], Danish Nachiangmai[6], Sirawit Jirawannaporn[7]
[1] Mathayom Taksin Rayong School, [2] Samsenwittayalai school, [3] Satriwithaya School, [4] Satit Prasarnmit International Programme of Srinakharinwirot University Prasarnmit Demonstration School (Secondary), [5] Assumption college, [6] Wichai Wittaya School, [7] Independent Researcher

Corresponding author: nicspayne@gmail.com

Received 2024 Feb 23, Revised 2024 Mar 18, Accepted 2024 Mar 22
DOI: 10.14456/iudcj.2024.16

บทคัดย่อ

โรคติดเชื้อมีความเสี่ยงต่อสุขภาพของประชากรทั่วโลกและเครื่องมือวินิจฉัยเป็นสิ่งสำคัญในการตรวจหาการติดเชื้อ การเข้าถึงวิธีการตรวจเชื้อมาตรฐานโดยเฉพาะอย่างยิ่งในโรงพยาบาลที่อยู่ห่างไกลและไม่มีความพร้อมทางด้านเครื่องมือเป็นเรื่องยาก ดังนั้นการตรวจเชื้อ ณ จุดดูแลผู้ป่วยจึงมีประสิทธิภาพ แม้ว่าการอ่านผลตรวจจะมีแนวโน้มที่จะไม่ถูกต้องและเสี่ยงต่ออคติ ดังนั้น

จุดมุ่งหมายของบทความปริทัศน์นี้คือเพื่อแสดงให้เห็นถึงความสำคัญของการใช้ปัญญาประดิษฐ์ (Artificial Intelligence; AI) เพื่อช่วยในการวินิจฉัยโรคติดเชื้อ

ระบบปัญญาประดิษฐ์ (AI) มีศักยภาพที่จะยกระดับการตรวจโรคและช่วยเหลือในการวิเคราะห์ผลได้ แม้ปัจจุบันจะมีข้อจำกัดอยู่ก็ตาม การเรียนรู้ของเครื่อง (Machine learning ;ML) สามารถช่วยแก้ไขปัญหาเหล่านี้ได้ ดังนั้นระบบปัญญาประดิษฐ์ (AI) และการเรียนรู้ของเครื่อง (ML) มีบทบาทสำคัญในการวินิจฉัยทางการแพทย์ การรักษา และการประเมินโรค ถึงแม้ว่าจะมีข้อจำกัดบางประการ เช่น การข้อมูลที่ใช้ในการพัฒนามีไม่พอ ความต้องการฟังก์ชันการทำงานที่เพิ่มขึ้น และการขาดความเข้าใจในการนำปัญญาประดิษฐ์ของบุคลากรทางการแพทย์มาใช้งานจริง

โดยสรุปแล้วปัญญาประดิษฐ์ (AI) มีความสามารถในการช่วยวินิจฉัยโรคติดเชื้อโดยใช้วิธีการเรียนรู้ของเครื่อง (ML) ที่ช่วยเพิ่มความแม่นยำ,ประสิทธิภาพและการเข้าถึงข้อมูลพร้อมศักยภาพในการพัฒนาต่อยอดเพิ่มเติมในอนาคตได้

คำสำคัญ : ปัญญาประดิษฐ์, โรคติดเชื้อ, การเรียนรู้ของเครื่อง, การวินิจฉัย, การตรวจจับ, วิทยาการระบาด

Abstract

Infectious diseases present a global risk, and diagnostic tools are crucial for identifying infections. Accessing traditional methods, especially in remote hospitals, is difficult. Point-of-care testing (POCT) is efficient, although their interpretation is prone to inaccuracies and prejudice. The aim of this review article is to demonstrate the significance and use of Artificial Intelligence (AI) in aiding the diagnosis of infectious illnesses.

AI has the potential to enhance disease surveillance, although it is currently constrained by constraints. Machine learning (ML) can address these challenges. AI and ML might become the main emphasis in medical diagnosis, treatment, and assessment. Challenges such as restricted data availability, the requirement for supplementary models, and a lack of understanding among AI professionals impede the use of AI technologies in healthcare.

In conclusion, AI has the ability to help diagnose infectious diseases using machine learning approaches, offering accuracy, effectiveness, and data accessibility, with opportunities for additional progress.

Keywords: Artificial Intelligence, Infectious diseases, Machine learning, Diagnosis, Detection, Epidemiology

Introduction

Infectious diseases pose a substantial risk to worldwide populations and are caused by a variety of pathogens such as bacteria, fungi, viruses, prions, and protozoa. New pathogens such as bacteria, viruses, fungi, and parasites are uncovered frequently (1). One of the tools we use for prevention is a diagnostic tool (2). Rapid and accurate diagnosis of infectious diseases is crucial as early detection can enable early and precise treatment, thus improving the disease prognosis (2). Undiagnosed individuals possess the potential to transmit diseases and evade quarantine or isolation, leading to an uncontrolled outbreak. The significance of diagnosing infectious diseases (3). The difficulty in diagnosing these diseases is since they manifest similar clinical symptoms, making laboratory diagnosis crucial. Nevertheless, accessing most conventional techniques can be challenging, particularly in hospitals located in rural areas. Point-of-care tests (POCT) have proven highly efficient for disease screening. Interpreting results, whether by medical or non-medical individuals, can be susceptible to bias or misinterpretation (4). Artificial Intelligence (AI) is now recognized as a valuable tool in the field of medical research, serving as an assistant. This review focuses on the utilization of AI to enhance the creation of improved diagnostic tools and to serve as an aid in interpreting results, thereby mitigating bias (5). We proposed the prospective utilization of AI and its potential as a formidable instrument in the times to come and future direction of AI including the possible issues

Material and Methods

This literature study collected information on the utilization of AI and ML from a variety of sources, such as medical publications and academic research. All of these studies were done between 2014 and 2023 to get current knowledge. The review includes key subjects such as definition, infectious illnesses diagnostics, artificial intelligence (AI), and machine learning (ML). The primary resources are the National Library of Medicine, National Center for Biotechnology Information, BMJ, Pathobiology of Human Disease, Immunology and Infection, Diagnostic Microbiology and Infectious Disease, Asian Journal of Pharmaceutical and Clinical Research, and Frontiers in Medicine.

1. The significance of infectious disease diagnosis.

Infectious disease diagnosis is crucial for preventing disease transmission and outbreaks. Diagnostic the disease early since the symptoms show can prevent a further spreading of infectious disease. Against ignoring the symptoms based on the Coronavirus disease (COVID-19) situation, people unaware of their symptoms and continuing with their daily routines, thereby increasing the risk of spreading the disease to others [6].The viral particles can be expelled from an infected person's mouth or nose in small liquid particles when they cough, sneeze, speak, sing, or breathe. Another person can then contract the virus when infectious particles that pass through the air are inhaled at short range (this is often called short-range aerosol or short-range airborne transmission) or if infectious particles come into direct contact with the eyes, nose, or mouth (droplet transmission). Previous studies have shown early detection of COVID-19 reduced the number of infected individuals significantly [7]. Furthermore, in leptospirosis, various reports indicated that early detection led to effective vectors such as mice and livestock isolation and elimination. Compare with the Infectious diagnosis in the past [8]. The history of the world is intertwined with the impact that infectious diseases have had on populations. Evidence of smallpox has been found in 3000-year-old Egyptian mummies. Egyptian papyrus paintings depict infectious diseases such as poliomyelitis. Hippocrates wrote about the spread of disease by means of air, water, and places, and made an association between climate, diet, and living conditions. Investigators described miasmas as the source of infections. Fracastoro discussed the germ theory in the 1500s and three routes of contagion were proposed including direct contact, fomites, and contagion from a distance (airborne). Epidemics of leprosy, plague, syphilis, smallpox, cholera, yellow fever, typhoid fever, and other infectious diseases were the norm [9].

In the present is easier to transport or communicate above the country or places, but it is also easier to access a diagnosis test according to in the last two decades there have been dramatic advances in development of rapid diagnostic tests. Turnaround time of the assays have significantly been shortened which led to reductions in time to appropriate antimicrobial therapy and improvement of patient clinical outcomes. Molecular-based assays generally have better sensitivity than conventional methods, but the cost is higher. The results need to be interpreted cautiously as detection of colonized organisms, pathogen detection in asymptomatic patients, and false negative/positive can occur. Indications and cost-effectiveness need to be considered for appropriate utilization of rapid diagnostic tests [(10)].

Showing uncommon symptoms, then quickly goes diagnosis disease can defense the infection to the social and get the right treatment according to the pathogens. Treatment of infectious diseases results in improved outcomes the sooner they are diagnosed, diagnosing infectious diseases assists in preventing the spread, and results in improved outcomes after getting treatment. Getting treatment sooner will lead to quicker initiation of appropriate antimicrobial therapy, improved patient clinical outcomes and pay lower healthcare costs. Various infectious diseases share common clinical manifestations namely, headache, fever, cough, sneezing. In addition, bacteria, virus, or fungus could be the catch of those common symptoms. Thus, the laboratory diagnosis is important and leads to rational drug use because each pathogen requires different drug and further prevent drug resistant strain of pathogens. The previous studies demonstrated the efficiency of early treatment of leptospirosis led to better clinical outcomes comparing with later treatment [(11)].

2. Challenges in diagnosing infectious diseases.

Numerous pieces of evidence indicated that many infectious diseases have similar clinical manifestations. A comprehensive analysis underscores the commonality in clinical presentations across various infectious diseases, shedding light on the intricate interplay of pathogens and host responses. This wealth of information underscores the imperative for enhanced diagnostic precision and therapeutic strategies to address the nuanced similarities observed in the clinical landscape of diverse infectious diseases [(12)].

As discerned from the evidence, the sole reliable method for accurate identification of infectious diseases necessitates the utilization of gold standard diagnostic testing approaches. The challenges associated with reaching this pinnacle in diagnostic precision are intricately intertwined with the evolving nature of infectious agents, the diverse array of pathogens, and the dynamic patterns of disease emergence. Furthermore, the need for continual refinement of diagnostic modalities in response to the ever-changing infectious disease landscape, underscores the persistent efforts required to overcome the challenges inherent in achieving and sustaining gold standard diagnostic methods. Through an in-depth analysis, it is evident that the pursuit of gold standard diagnostic accuracy is an ongoing endeavor that demands collaborative research, technological advancements, and a nuanced understanding of the intricate interactions between pathogens and host responses [13].

Arising from the imperative of addressing this particular challenge, the development and implementation of POCT emerged as a pivotal solution for conducting preliminary screenings. The significance of point-of-care tests as a frontline tool in rapidly and accurately screening for infectious diseases. This approach not only facilitates prompt diagnosis but also holds relevance in resource-limited settings where access to sophisticated diagnostic facilities may be constrained. The multifaceted advantages of POCT, encompass its ability to provide real-time results, enhance patient outcomes, and streamline healthcare delivery by expediting the initiation of targeted therapeutic interventions, and advancements that contribute to heightened sensitivity, specificity, and overall diagnostic accuracy. The constant innovation and refinement discussed in the scholarly work reinforce the dynamic nature of point-of-care testing methodologies, emphasizing their adaptability to diverse infectious disease scenarios [14].

The usage of POCT are widely spread in common time, giving an instant would be the Antigen Rapid Test for the COVID-19, its remarkably quick and easy to use properties allow people to utilize it and rely on its diagnosis of the disease COVID-19 [16]. POCT devices are developed to improve the patient's health management, prognosis, and to also control the transmission of diseases. The utilization of Antigen Rapid Tests offered by POCT are portable, affordable, and rapid. Surpassing the effectiveness of conventional methods which are more time consuming, expensive, and require more skilled personnel. In spite of that, many studies have shown that POCT devices do not meet the criteria created by the World Health Organization (WHO), mainly because of the majority of their lack of required accuracy which could lead to errors in diagnosis and treatment [4].

3. The application of AI to infectious disease diagnosis.

AI methods have been utilized in diagnostic medicine for several decades, especially in image analysis and clinical diagnosis [5,17]. During the COVID-19 pandemic, AI contributed a crucial part in genome sequencing, medications and vaccine research, illness outbreak detection, disease spread monitoring, and SARS-CoV-2 new variants tracking. AI-driven initiatives complement human-curated ones, such as conventional public health surveillance. Preparing for future pandemics will necessitate the combined efforts of collaborative surveillance networks, which currently include the US Centers for Disease Control and Prevention (CDC) Center for Forecasting and Outbreak Analytics and the WHO Hub for Pandemic and Epidemic Intelligence, which will use AI in surveillance programs in conjunction with international cooperation [18]. This article aims to provide an update on the applications and restrictions of AI in infectious disease monitoring and pandemic preparedness.

The AI algorithm-implemented Loop-mediated Isothermal Amplification LAMP (ai-LAMP) test, targeting the RNA-dependent RNA polymerase gene, demonstrated excellent analytical sensitivity and specificity for SARS-CoV-2. The platform analyzed around 200 NHS patient samples for suspected COVID-19 and shown to be more reliable, specific, and sensitive than the existing gold standard quantitative reverse transcription-polymerase chain reaction (qRT-PCR). As a result, our approach has the potential to provide an efficient and cost-effective platform for detecting SARS-CoV-2 in laboratories with limited resources [19].

The intersection of AI and healthcare has paved the way for transformative advancements, particularly in the realm of infectious disease diagnosis. This article delves into the multifaceted applications of AI in identifying, diagnosing, and managing infectious diseases, showcasing the promising strides made in recent years.

3.1 Image Analysis in Medical Imaging: AI algorithms have exhibited exceptional capabilities in the analysis of medical images, including X-rays, CT scans, and MRIs. These algorithms can swiftly and accurately identify patterns associated with infectious diseases, aiding in the prompt diagnosis of conditions such as pneumonia, tuberculosis, and respiratory infections.

3.2 Diagnostic Algorithms and Machine Learning Models: Leveraging machine learning, AI systems are designed to recognize patterns within clinical data, patient history, and laboratory results. These diagnostic algorithms contribute to the early detection and precise diagnosis of infectious diseases, offering a valuable tool for healthcare professionals. Previous research used AI and machine learning models in POCT results interpretation[20] accurate, and low-cost detection of SARS-CoV-2 is crucial to contain the transmission of COVID-19. Here, we present a cost-effective smartphone-based device coupled with machine learning-driven software that evaluates the fluorescence signals of the CRISPR diagnostic of SARS-CoV-2. The device consists of a three-dimensional (3D, and detection of the coughing pattern in order to identify the probability of a potential pathogen [21].

3.3 Genomic Analysis for Pathogen Identification: AI plays a pivotal role in genomic medicine by analyzing vast datasets to identify and understand the genetic makeup of pathogens. This has significant implications for infectious disease diagnosis, allowing for rapid and accurate identification of causative agents, leading to more targeted treatment strategies.

3.4 Epidemiological Surveillance and Predictive Modeling: AI-driven predictive modeling has proven instrumental in monitoring and predicting the spread of infectious diseases. By analyzing real-time data from diverse sources, including social media and healthcare databases, AI assists public health authorities in implementing timely and effective interventions.

3.5 Chatbots and Virtual Assistants for Symptom Analysis: The integration of AI-powered chatbots and virtual assistants provides a user-friendly platform for individuals to assess their symptoms. These tools, utilizing AI algorithms, offer valuable preliminary insights, guiding individuals on whether to seek medical attention or engage in self-care measures.

3.6 Drug Discovery and Antigen Identification: AI accelerates drug discovery by sifting through vast datasets to identify potential drug candidates for infectious diseases. Additionally, AI aids in the identification of antigens, crucial for the development of vaccines against emerging infectious threats.

3.7 Real-time Data Analysis for Outbreak Monitoring: AI contributes to real-time data analysis, enabling the continuous monitoring of infectious disease outbreaks. This capability assists in the swift identification of hotspots, facilitating proactive public health measures to contain the spread of diseases.

3.8 Electronic Health Records (EHR) and Data Mining: AI's ability to mine valuable information from electronic health records enhances infectious disease research. By extracting insights from diverse patient records, AI supports epidemiological studies and the identification of risk factors associated with specific infectious diseases.

4. Future directions and challenges for AI in the diagnosis of infectious diseases.

AI refers to the simulation or approximation of human intelligence in machines. The goals of AI include computer-enhanced learning, reasoning, and perception. AI is being used today across different industries, from finance to healthcare [17].

AI algorithms and other applications powered by AI are being used to support medical professionals in clinical settings and in ongoing research. Currently, the most common roles for AI in medical settings are clinical decision support and imaging analysis [5].

With the projected increase in the global population, current healthcare delivery models will face severe challenges. Rural and remote areas, whether in developed or developing countries, are characterized by the same challenges: the unavailability of hospitals, lack of trained and skilled staff performing tests, and poor compliance with quality assurance protocols. POCT using AI is poised to be able to address these challenges. In this review, we highlight some key areas of application of AI in POCT, including lateral flow immunoassays, bright-field microscopy, and hematology, demonstrating this rapidly expanding field of laboratory medicine [22].

POCT, where patients are tested and treated at the hospital bedside, in pharmacies, at community centers, or in their own homes, provides a workable healthcare solution. One of the challenges in performing POC testing is ensuring that the results are reliable and correctly interpreted. This requires properly trained users and quality assurance practices. AI is making important contributions to POC testing and is expected to help resolve many of the challenges faced by healthcare workers and in the widespread application of direct-to-consumer testing. In this review, we highlight some important examples where AI facilitates developments in this rapidly expanding field [19,21,22].

The application of AI to infectious disease diagnosis. An enhanced and more powerful diagnostic tool for infectious diseases could help clinicians around the world better identify pathogens and provide appropriate treatments to patients in a timely manner. By leveraging machine learning techniques trained on vast clinical databases, AI systems may be able to recognize subtle patterns and indicators that human doctors could miss. This could allow for the diagnosis of certain diseases much earlier than current standard practices. For example, an AI tool that can efficiently analyze medical imagery, like x-rays or CT scans, may be able to spot signs of infection that a human reviewer did not notice during the initial examination.

Earlier detection leads to earlier treatment, which can make a huge difference in public health outcomes, especially for highly contagious or life-threatening diseases. While there are certainly challenges to developing highly accurate AI for medical use, the potential benefits could be enormous. With further refinements, such systems may become valuable allies for physicians worldwide in the ongoing fight against infectious illnesses[5].

With AI, vast amounts of data on everything from genetics and lifestyle to ambient pollution and socioeconomic factors will empower researchers and clinicians to zero in on a patient's unique risk of disease and the best course of prevention or treatment.

Conclusion

AI can assist in diagnosing infectious diseases through machine learning, utilizing various methods that leverage accuracy, speed, data, and the capacity for further development. In the near future, AI may be accessed through mobile devices, as manufacturers have made significant advancements in developing mobile phones and personal computers equipped with dedicated CPUs for AI. These devices can be utilized with or without an internet connection. Furthermore, the utilization of web-based or cloud-based AI necessitates an internet connection. This review indicates that AI may be useful in diagnosing infectious diseases and offers the potential for further development in the future.

แนะนำการอ้างอิงสำหรับบทความนี้

ศรัณยพงศ์ กุลภัทร์วัฒนา, ปิญชาณ์พัชร โพคะ, นิรดา แสงกิติโกมล, โปรดปราน คงชาตรี, นลิน องค์วุฒิธรรม, ศักรนันทน์ บูรณจิตร์ภิรมย์, ดานิฌ ณ เชียงใหม่, และคณะ. ปัญญาประดิษฐ์มีศักยภาพที่จะเอาชนะความท้าทายในการวินิจฉัยโรคติดเชื้อ. วารสารสถาบันป้องกันควบคุมโรคเขตเมือง. 2567;9(1):281-292.

Suggested citation for this article

Kulpatwattana S, Poka P, Sangkitikomol N, Kongchatree P, Ongwuthitham N, Boonranajitpirom S, Nachiangmai D, et al. Artificial intelligence (AI) has the potential to surpass the challenges in diagnosing infectious diseases. Institute for Urban Disease Control and Prevention Journal. 2024;9(1):281-292.

References

1. Abimbola Ayorinde, Iman Ghosh, Ifra Ali, Iram Zahair, Olajumoke Olarewaju, Megha Singh, et al. Health inequalities in infectious diseases: a systematic overview of reviews. BMJ Open. 2023 Apr1;13(4):e067429.
2. Walker DH. Principles of Diagnosis of Infectious Diseases. Pathobiology of Human Disease. 2014;222–5.
3. Lopera TJ, Alzate-Ángel JC, Díaz FJ, Rugeles MT, Aguilar-Jiménez W. The Usefulness of Antigen Testing in Predicting Contagiousness in COVID-19. Microbiol Spectr. 2022 Apr 27;10(2):e0196221.
4. Musso D, La Scola B. Laboratory diagnosis of leptospirosis: A challenge. Journal of Microbiology, Immunology and Infection. 2013 Aug 1;46(4):245–52.
5. Wong F, de la Fuente-Nunez C, Collins JJ. Leveraging artificial intelligence in the fight against infectious diseases. Science. 2023 Jul 14;381(6654):164–70.
6. Lotfi M, Hamblin MR, Rezaei N. COVID-19: Transmission, prevention, and potential therapeutic opportunities. Clin Chim Acta. 2020 Sep;508:254–66.
7. Polechová J, Johnson KD, Payne P, Crozier A, Beiglböck M, Plevka P, et al. SARS-CoV-2 rapid antigen tests provide benefits for epidemic control - observations from Austrian schools. J Clin Epidemiol. 2022 May;145:14–9.
8. Picardeau M, Bertherat E, Jancloes M, Skouloudis AN, Durski K, Hartskeerl RA. Rapid tests for diagnosis of leptospirosis: Current tools and emerging technologies. Diagnostic Microbiology and Infectious Disease. 2014 Jan 1;78(1):1–8.
9. Sakai T, Morimoto Y. The History of Infectious Diseases and Medicine. Pathogens. 2022 Oct 4;11(10):1147.
10. Shang M, Guo J, Guo J. Point-of-care testing of infectious diseases: recent advances. Sens Diagn. 2023 Sep 14;2(5):1123–44.
11. Costa E, Lopes AA, Sacramento E, Costa YA, Matos ED, Lopes MB, et al. Penicillin at the late stage of leptospirosis: a randomized controlled trial. Rev Inst Med Trop Sao Paulo. 2003;45(3):141–5.
12. Liang F, Wang X, Shao J, Chen J, Liu L, Li H, et al. Comparison of clinical features on admission between coronavirus disease 2019 and influenza a among children: a retrospective study in China. BMC Infect Dis. 2021 Apr 17;21:365.

13. Dong J, Olano JP, McBride JW, Walker DH. Emerging Pathogens: Challenges and Successes of Molecular Diagnostics. J Mol Diagn. 2008 May;10(3):185–97.
14. Lee S, Bi L, Chen H, Lin D, Mei R, Wu Y, et al. Recent advances in point-of-care testing of COVID-19. Chem Soc Rev. 2023 Dec 11;52(24):8500–30.
15. Pai NP, Wilkinson S, Deli-Houssein R, Vijh R, Vadnais C, Behlim T, et al. Barriers to Implementation of Rapid and Point-of-Care Tests for Human Immunodeficiency Virus Infection. Point Care. 2015 Sep;14(3):81–7.
16. Biswas A, Ray R, Khamrai A, Paul D. Performance of rapid antigen test in comparison to real-time RT-PCR in diagnosis of COVID-19 infection: A short study. Asian Journal of Pharmaceutical and Clinical Research. 2023 Jul 7;44–7.
17. Pandya S, Thakur A, Saxena S, Jassal N, Patel C, Modi K, et al. A Study of the Recent Trends of Immunology: Key Challenges, Domains, Applications, Datasets, and Future Directions. Sensors (Basel). 2021 Nov 23;21(23):7786.
18. Parums DV. Editorial: Infectious Disease Surveillance Using Artificial Intelligence (AI) and its Role in Epidemic and Pandemic Preparedness. Med Sci Monit. 2023 Jun 1;29:e941209.
19. Rohaim MA, Clayton E, Sahin I, Vilela J, Khalifa ME, Al-Natour MQ, et al. Artificial Intelligence-Assisted Loop Mediated Isothermal Amplification (AI-LAMP) for Rapid Detection of SARS-CoV-2. Viruses. 2020 Sep 1;12(9):972.
20. Samacoits A, Nimsamer P, Mayuramart O, Chantaravisoot N, Sitthi-amorn P, Nakhakes C, et al. Machine Learning-Driven and Smartphone-Based Fluorescence Detection for CRISPR Diagnostic of SARS-CoV-2. ACS Omega. 2021 Feb 2;6(4):2727–33.
21. Belkacem AN, Ouhbi S, Lakas A, Benkhelifa E, Chen C. End-to-End AI-Based Point-of-Care Diagnosis System for Classifying Respiratory Illnesses and Early Detection of COVID-19: A Theoretical Framework. Frontiers in Medicine [Internet]. 2021 [cited 2024 Feb 4];8. Available from: https://www.frontiersin.org/articles/10.3389/fmed.2021.585578
22. Khan AI, Khan M, Khan R. Artificial Intelligence in Point-of-Care Testing. Ann Lab Med. 2023 Sep 1;43(5):401–7.